

RCI Region IV Hawaii Winter Workshop



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Roof Consultants Institute

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January 22, 2007

Design of Exterior Wall Assemblies

By
Karim P. Allana, PE, RRC, RWC



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KARIM ALLANA, P.E., RRC, RWC

- **EDUCATION:** B.S., Civil Engineering, Santa Clara University, 1983
- **REGISTRATION:** P.E., Civil Engineering, California, 1987
P.E., Civil Engineering, Nevada
P.E., Civil Engineering, Hawaii
- **CERTIFICATION:** Registered Roof Consultant (RRC), Roof Consultants Institute
Registered Waterproofing Consultant (RWC), Roof Consultants Institute
- **OVERVIEW:**
 - Over 20 years experience providing technical standards in building envelope technology.
 - Expert Witness in Construction Defect Litigation
 - Principal consultant in design of building envelope, roofing and waterproofing systems, forensic investigations of building assemblies and failure analysis.
 - Expert in all aspects of building envelope technology.
 - Specialization in cement plaster, other siding types, roofing, wood, water intrusion damage, window assemblies, storefronts, below grade waterproofing, and complex assemblies.
 - Completed over 1300 projects: new construction, addition, rehabilitation, remodel and modernization projects for public and private sector clients.



OVERVIEW

➤ Review of Exterior Wall Assemblies

- Barrier Wall Systems
- Rain Screen Principal
- Drainable Wall Assemblies
- Metal Wall Panels
- Cement Plaster
- EIFS



OVERVIEW

- Address the effects of moisture movement in wall assemblies
 - Principles of water phases, relative humidity, condensation, vapor retarders and vapor pressure
 - Examples of condensation caused by vapor transmission through interior and exterior walls, indoor showers, pools and spas
- Calculations for moisture diffusion through cement plaster wall assembly.
- EIFS Bullnose failure study



OVERVIEW

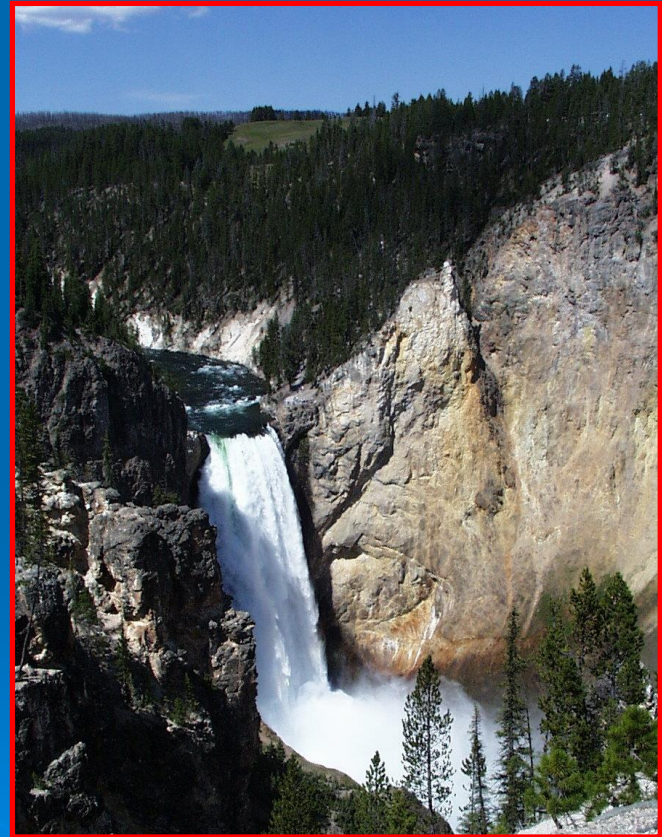
- Material Selection for Exterior Wall
 - Selection of Sustainable Materials
 - Materials less prone to mold and water damage
 - Selection of Vapor Retarders
 - Selection of Sealants for Exterior Wall



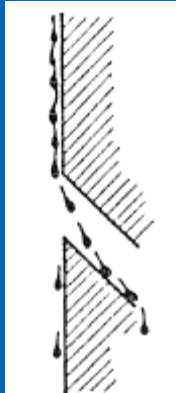
Wall Design

Three Key Elements of a Wall Leaks:

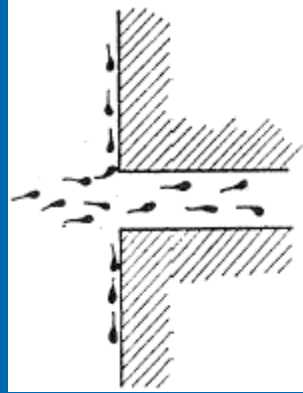
- Water
- Opening in Wall
- Forces to drive water through the opening



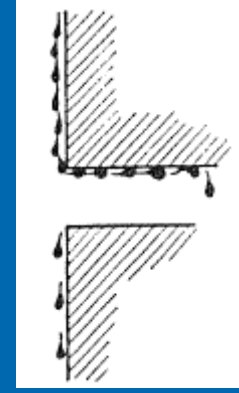
Typical Forces in Nature that Cause Water Intrusion Through Wall Assemblies



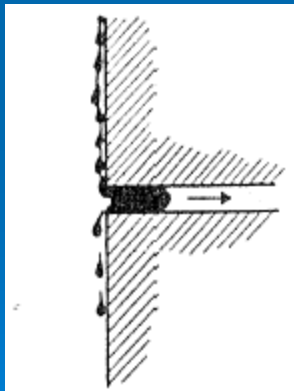
Gravity



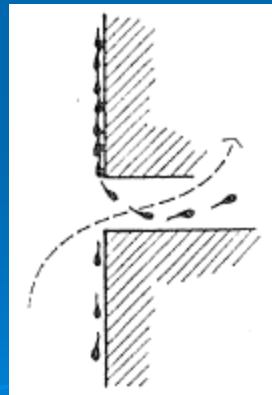
Kinetic Energy



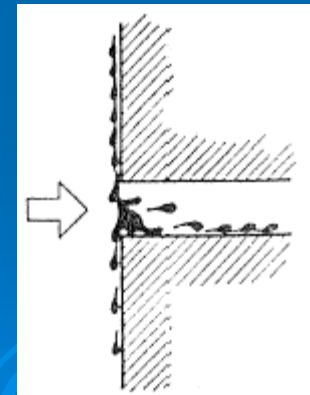
Surface Tension



Capillary Action



➤ Air Current



Pressure Differential



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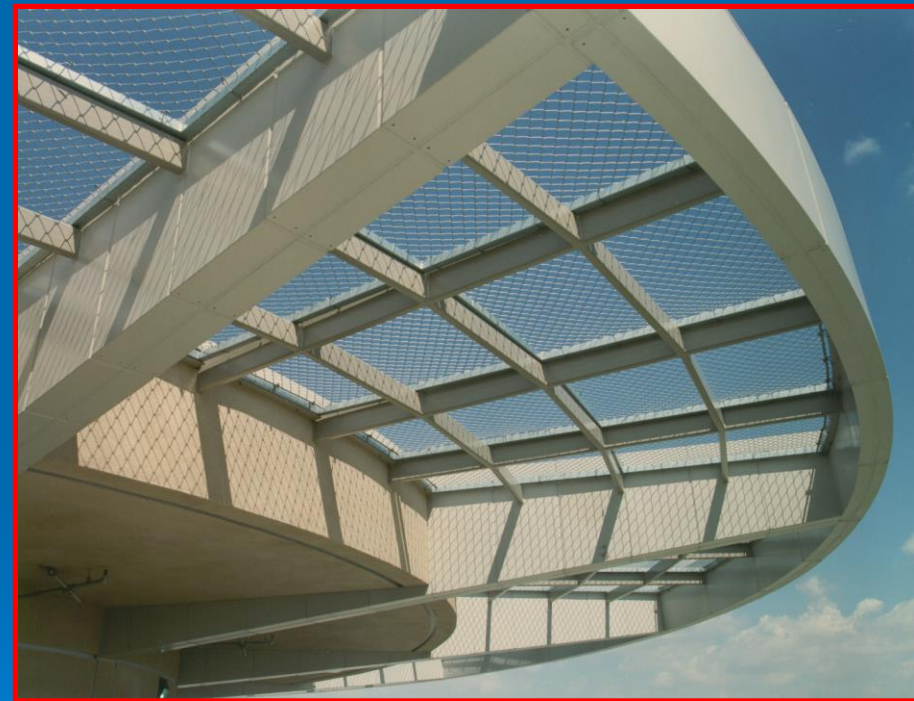
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Wall Design

Philosophy Behind Barrier Wall Systems

:

- We can't do anything about the water!
- We can't do anything about the forces that drive water through the opening!
- We are going to seal every opening!!!



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BARRIER WALL ASSEMBLIES

- When exterior skin/mass is designed to be the only water barrier.
- Examples:
 - Traditional Exterior Insulation & Finish (EIFS)
 - Mass Masonry Walls
 - Certain types of Curtain Wall
 - Cast in Place (CIP) Concrete Wall



Barrier Wall Systems



Barrier Metal Panels



Pre-cast Concrete



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Traditional EIFS is a Barrier Wall



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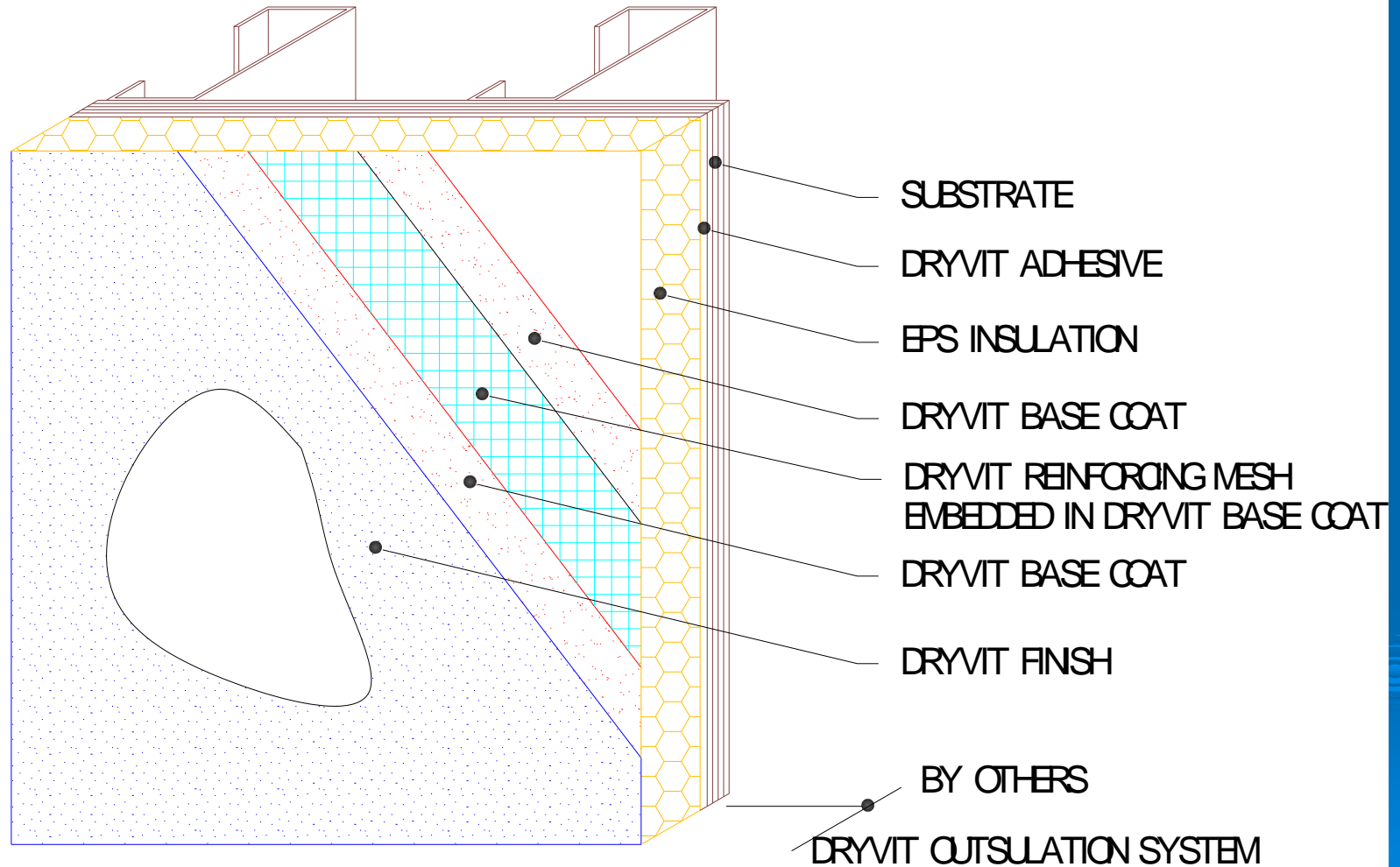
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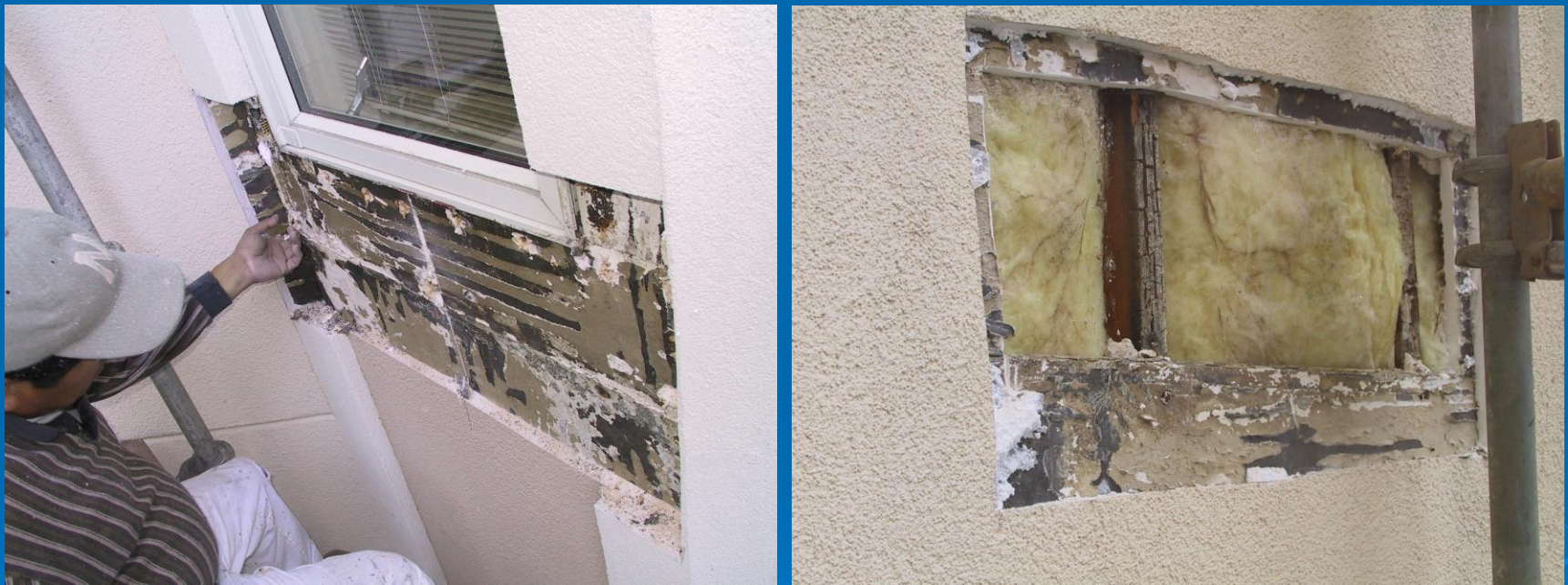
EIFS



BARRIER WALL SYSTEM



EIFS Wall, Perimeter Sealants are Critical for Preventing Water Intrusion in Barrier Wall



1/8" to 3/32" thick EIFS lamina consisting of polymer modified cement and fiberglass is the "Water Barrier"



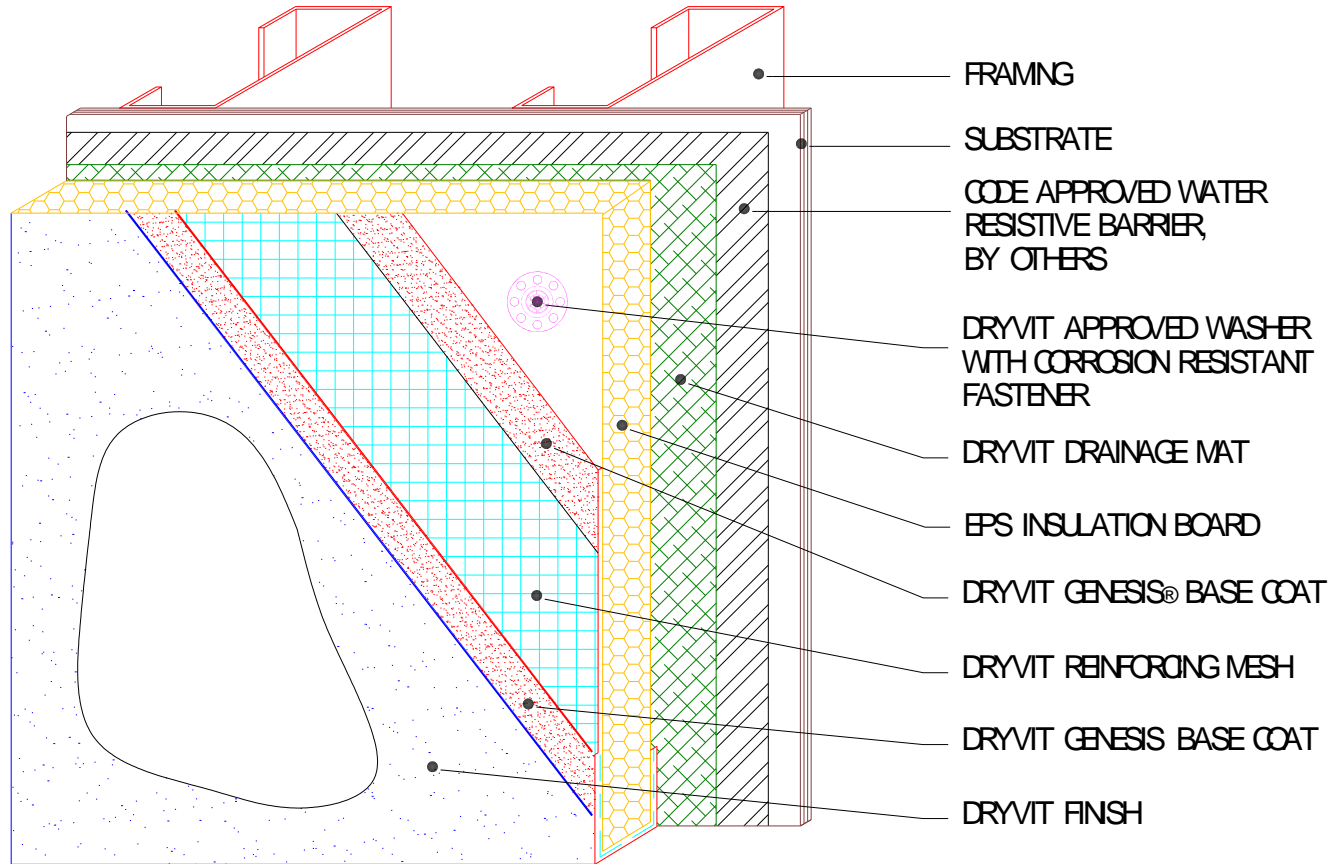
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EIFS Moisture Drained System



DRAINAGE MAT OPTION
(SYSTEM 1)



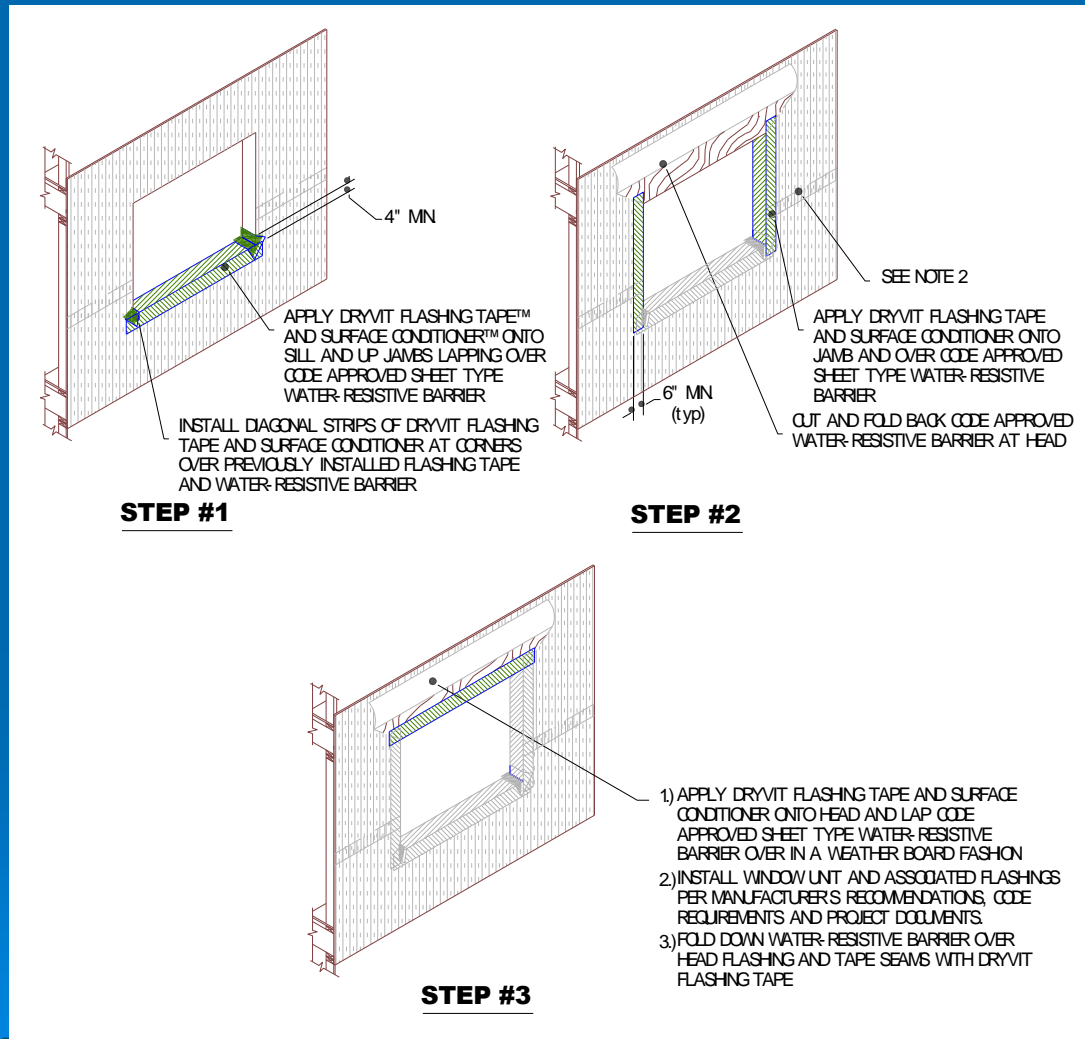
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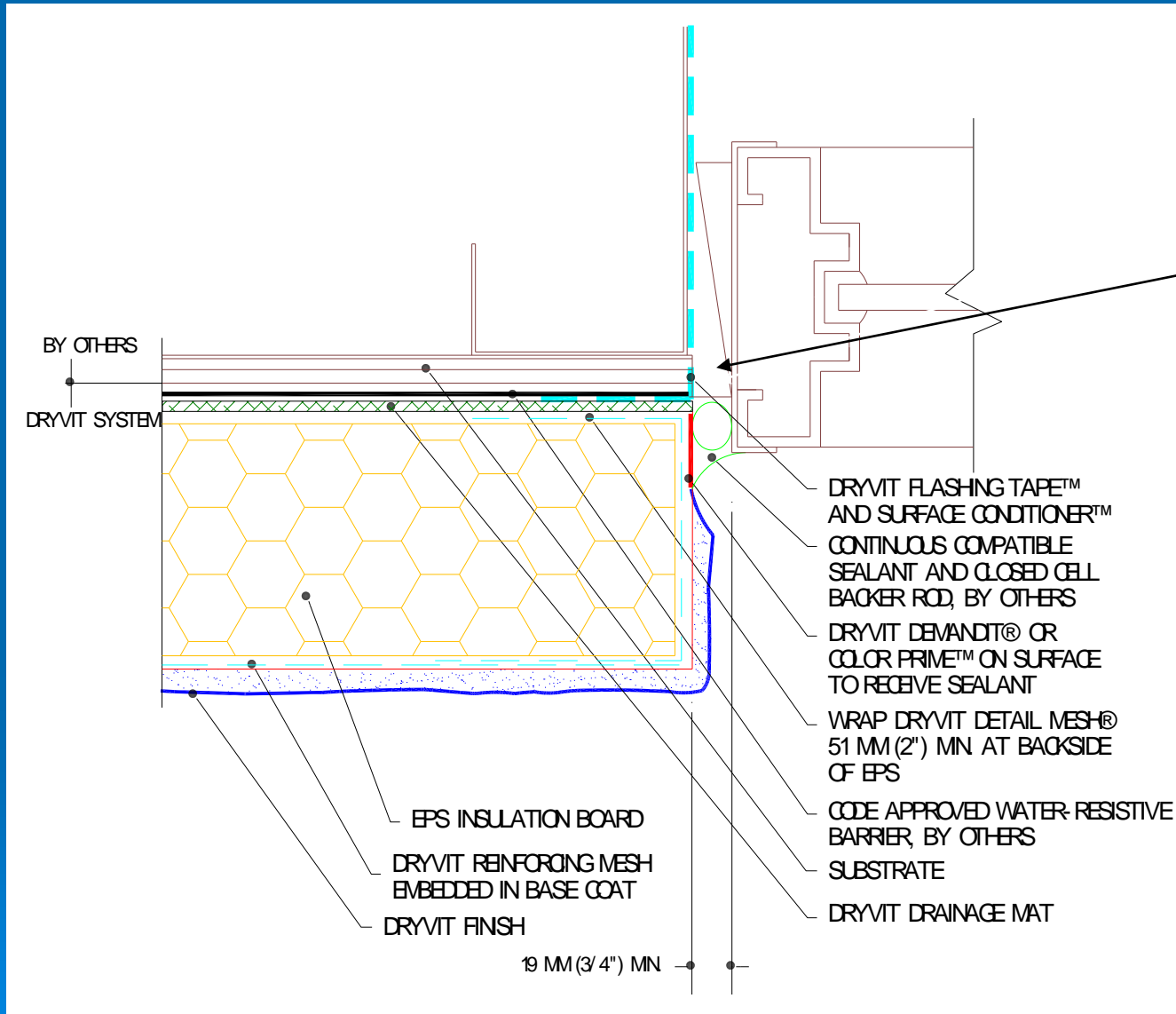


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EIFS Moisture Drained Window



EIFS Moisture Drained Window Jamb



Manufacturer's
standard Detail
is Missing
Secondary Seal
to Water
Resistive Barrier



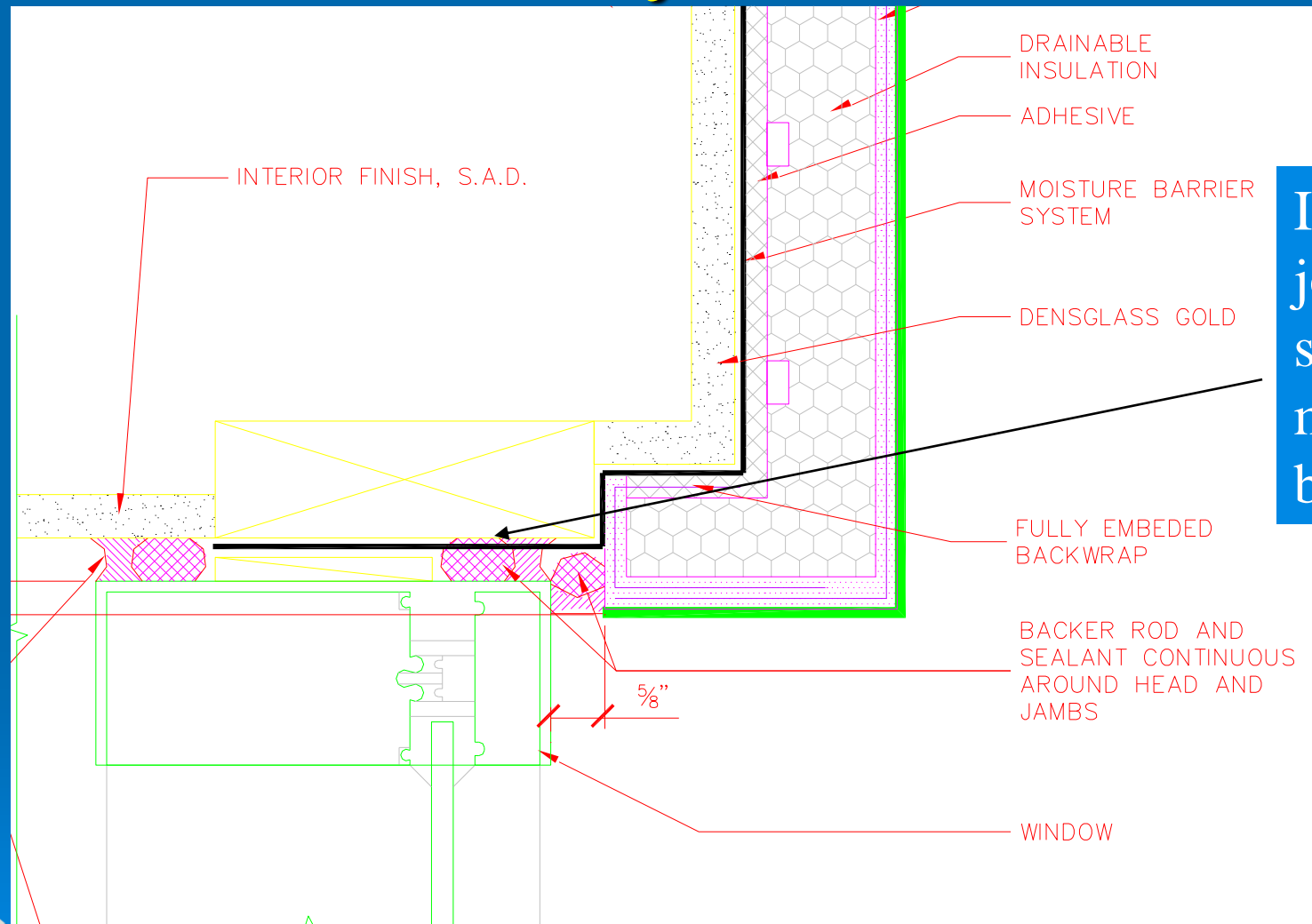
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Drainable EIFS Window Jamb With Secondary Sealant Joint



Inside sealant joint to seal secondary moisture barrier



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Wall Design

Philosophy Behind Back Ventilated Rainscreen Systems :

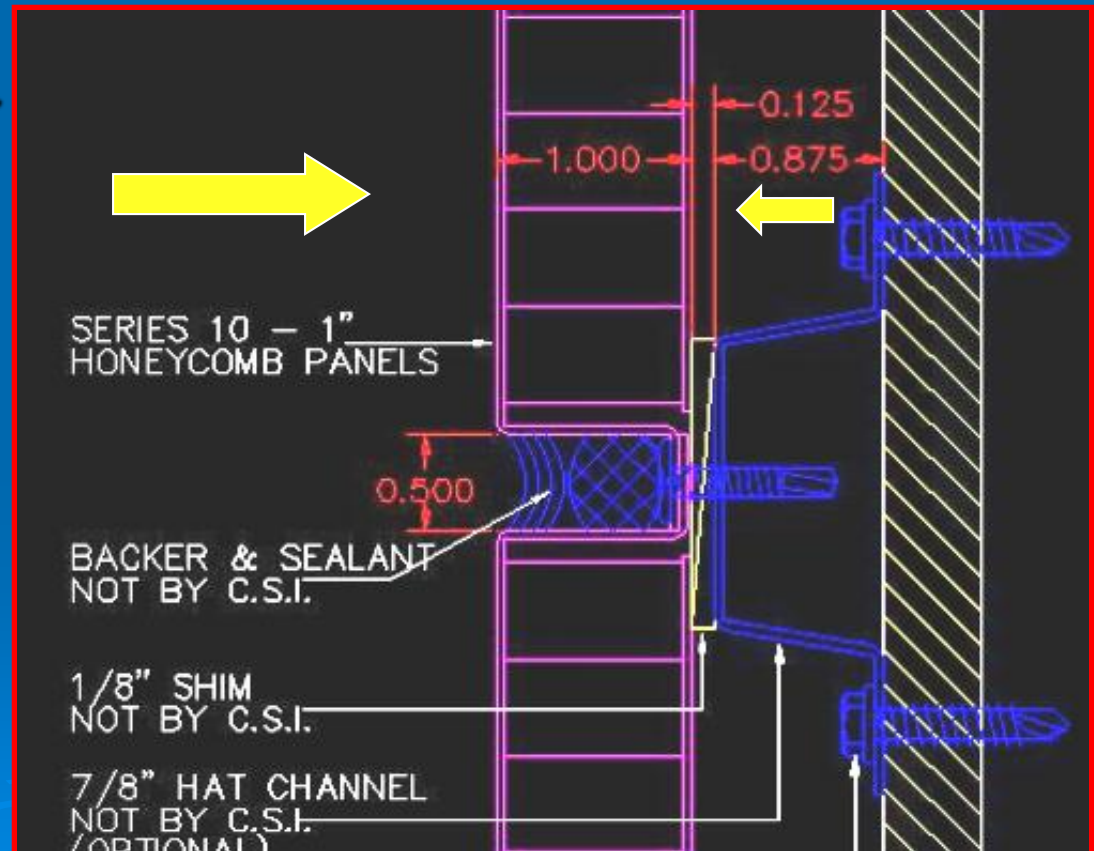
- Counteract the driving force behind water intrusion, i.e. Pressure Differential
- Equalize the pressure between the outside skin and inside face of panel
- Cavity behind the panel or masonry with vents to equalize pressure



Pressure Differential

➤ Cavity Wall

- Pressure is greater on the outside of the wall because it is completely sealed!



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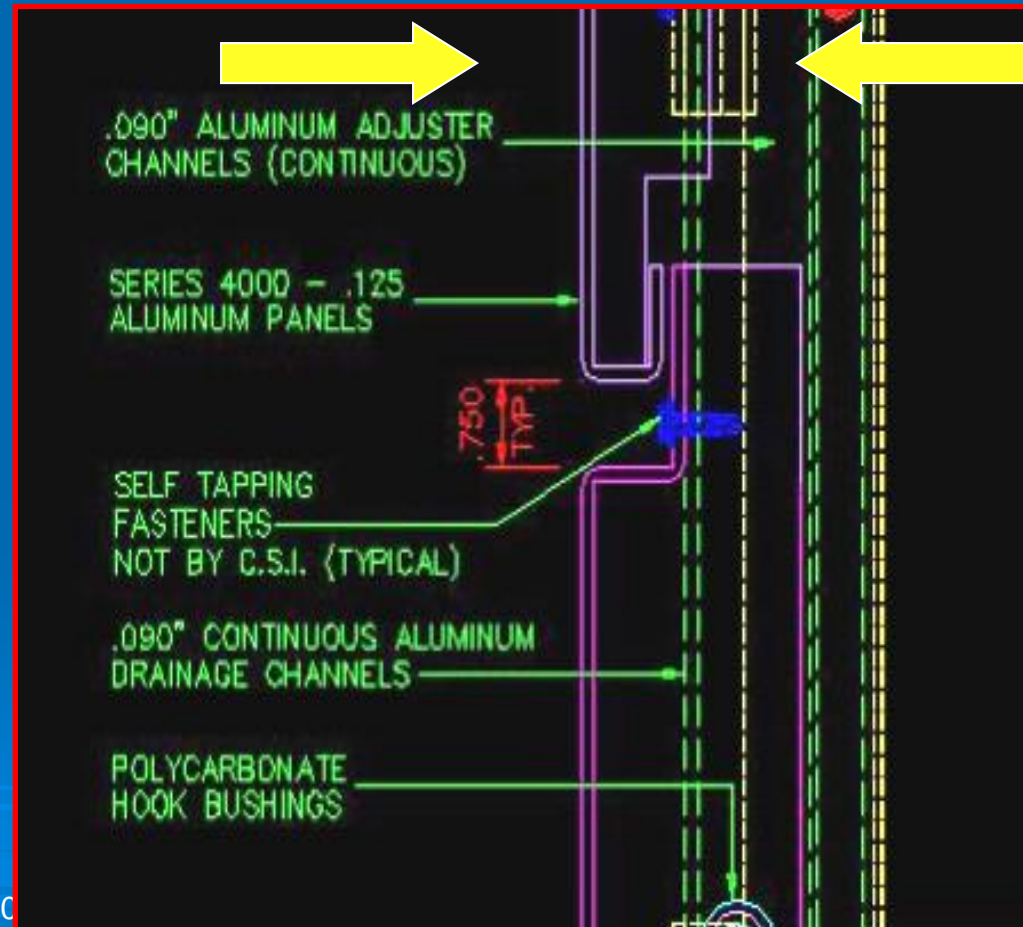
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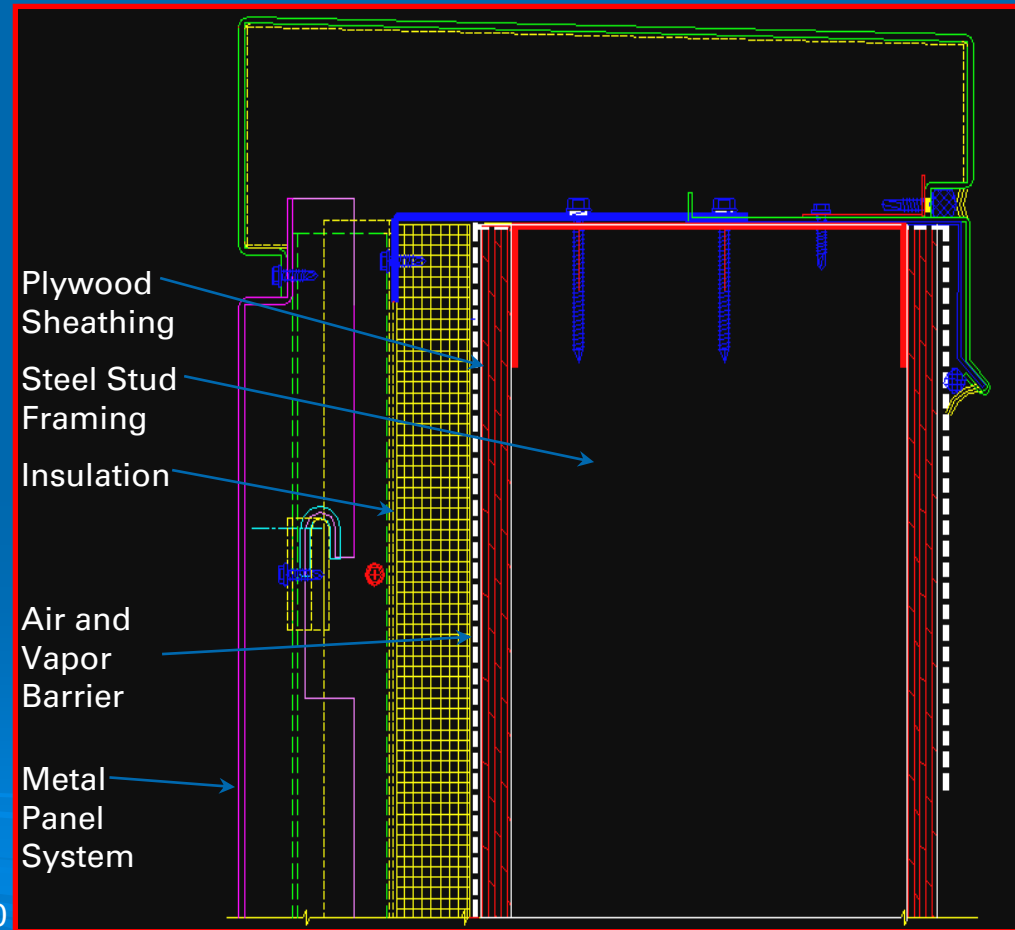
Pressure Differential

- Back Ventilated
- Rainscreen Wall
- In a Back Ventilated System the joints are open. Therefore, the pressure on the back side of the



Wall Design

- Back Ventilated
- Rainscreen Systems
- The air barrier behind the panels is a vapor barrier. The design professional needs to take this into consideration when designing a back ventilated rainscreen system.



Austin-Bergstrom International Airport, Austin, TX

Open Joint Rainscreen System in Aluminum Plate
Kynar Finish



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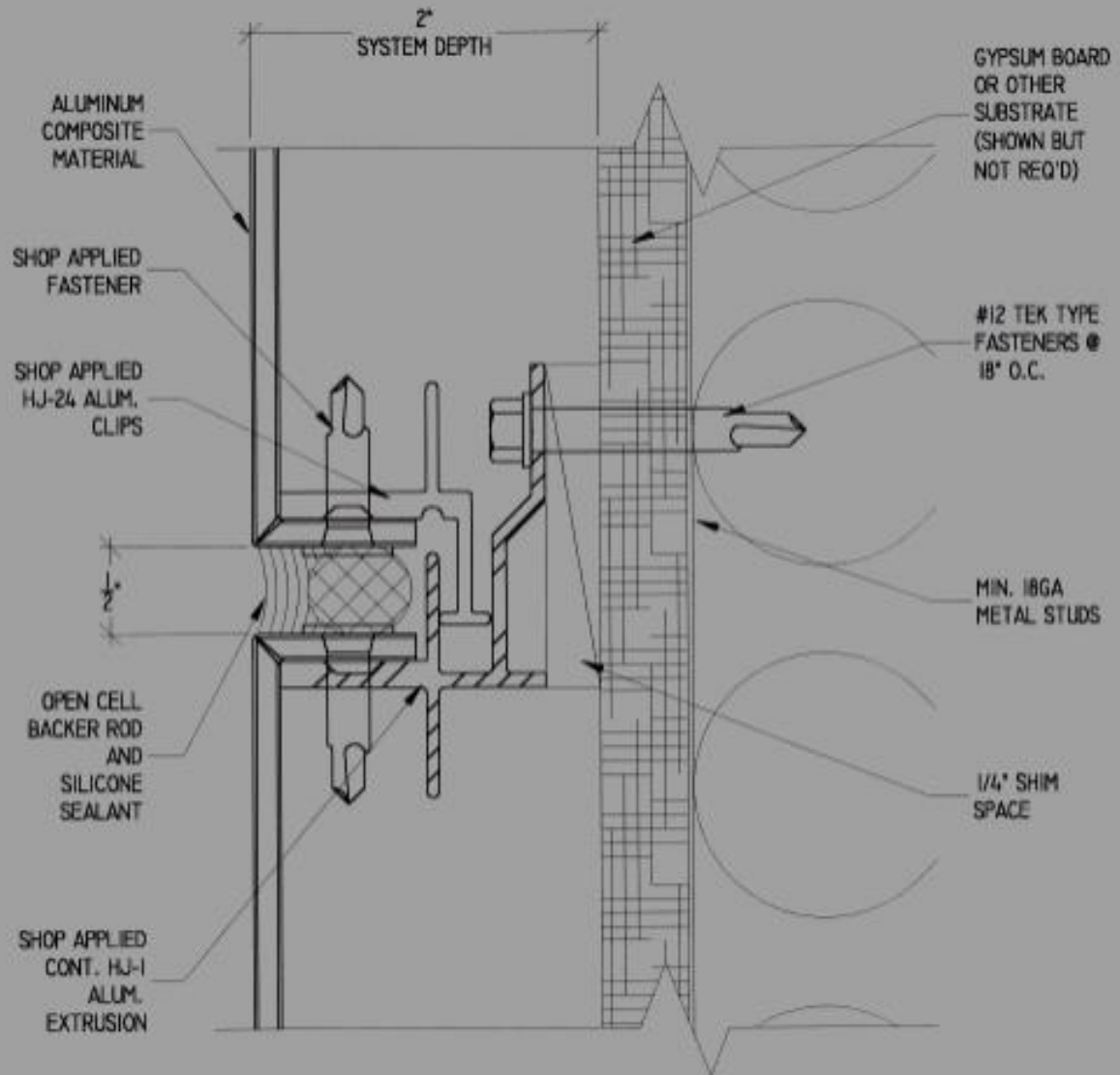
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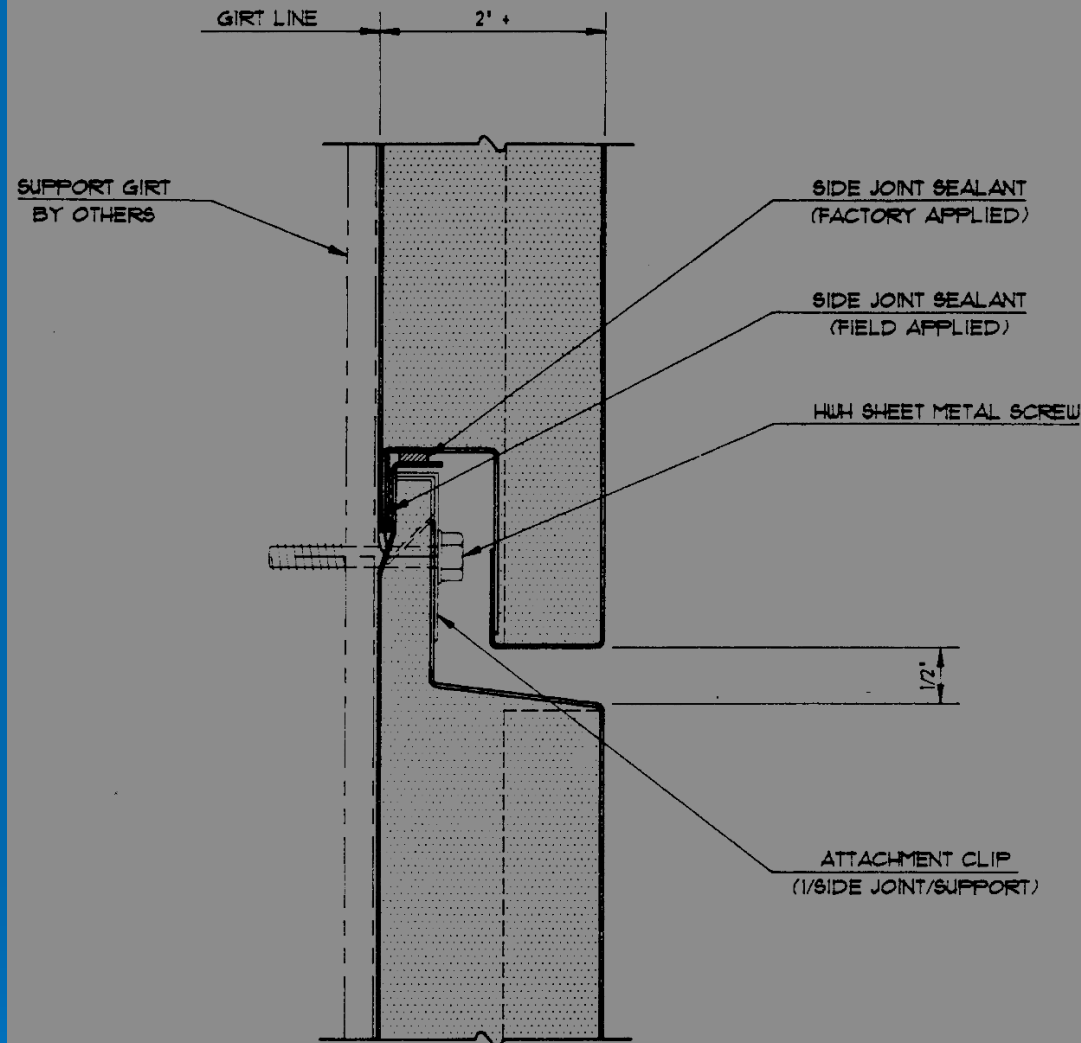
What Kind of Metal Panel?

- Barrier or Rainscreen Wall?
- Sequential Installation?



What Kind of Metal Panel?

- Barrier or Rainscreen Wall?
- Sequential Installation?



TYPICAL PANEL HORIZONTAL (SIDE) JOINT



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BUILDING AREAS SUSCEPTIBLE TO CONDENSATION

- Compact roof assemblies, i.e., no attic – flat roofs or cathedral ceilings
- Exterior wall assemblies with large temperature difference between outside and inside
- Interior wall assemblies with humidity and temperature difference



AREAS SUSCEPTIBLE TO MOISTURE ACUMULATION

- Exterior wall assemblies
- Interior wall assemblies
- Chilled water line insulation
- Indoor pools and spas



Effects of Moisture Movement in Wall Assemblies

- Address the Principles of water phases, relative humidity, condensation, vapor retarders and vapor pressure
 - Common modes of water movement through cement plaster and modes of drying.
 - Examples of condensation caused by vapor transmission through exterior walls



Relevant Terminology:

- WATER PHASES
- RELATIVE HUMIDITY
- CONDENSATION
- WATER VAPOR TRANSMISSION
- PERMEANCE/PERMEABILITY
- VAPOR PRESSURE
- DIFFUSION



WATER PHASES

- Water can exist in three phases
 - Ice
 - Liquid, between 32 degrees (freezing) and 212 degrees F (boiling)
 - Gas phase (steam) from boiling, or gas phase (water vapor) from evaporation, when the temperature is below boiling point
- When cooled, water vapor will lose energy and return to liquid, i.e., it will condense



RELATIVE HUMIDITY

- The amount of water in its gaseous phase that can be contained within a given volume of air is a function of the air's temperature:
 - Warm air holds more moisture than cold air!!
- Relative humidity is expressed as a percentage: 100% humidity means that the air is saturated at that temperature



DIFFUSION/PERMEABILITY

- Diffusion is the transmission of water vapor through a material
- Some materials allow diffusion to occur more rapidly than others
- A material's ability to allow diffusion of water vapor is measured by “permeability” and “permeance”



PERMEANCE

- Permeance is based on given thickness of material.
 - Unit of measure = Perm
 - Is measured in perms per square meter
 - Rating under 0.5 = vapor barrier



PERMEABILITY

- Permeability is based on a given thickness range of material.
 - Unit of measure = Perm.inch
 - Example, Permeability of concrete = 3.2 perm.in
 - Permeance of 6" thick concrete slab = $3.2 \text{ perm.in} / 6" = .53 \text{ perm}$



Figure 5

Typical Water Vapor Permeance and Permeability Values ^{1,2}		
Material	Permeance (perm)	Permeability (perm•in)
Common roof membrane materials:		
Asphalt (hot applied, 2 lbs/100 ft ²)	0.5	
Asphalt (hot applied, 3.5 lbs/100 ft ²)	0.1	
Built-up membrane (hot applied)	0.0	
No. 15 asphalt felt	1.0	
No. 15 tarred felt	1.0	
Roll roofing (saturated and coated)	0.05	
Common insulation materials:		
Expanded polystyrene insulation		2.0 - 5.8
Extruded polystyrene insulation		1.2
Plastic and metal films and foils:		
Aluminum foil (1 mil)	0.0	
Kraft paper and asphalt laminated, reinforced	0.3	
Polyethylene sheet (4 mil)	0.08	
Polyethylene sheet (6 mil)	0.06	
Other common construction materials:		
Brick masonry (4 in. thick)	0.8	
Concrete (1:2:4 mix)		3.2
Concrete block (with cores, 8 in. thick)	2.4	
Gypsum wall board (plain, 3/4 in. thick)	50	
Hardboard (standard, 1/2 in. thick)	11	
Metal roof deck (not considering laps and joints)	0.0	
Plaster on metal lath	15	
Plaster on wood lath	11	
Plywood (Douglas fir, exterior glue, 1/2 in. thick)	0.7	
Plywood (Douglas fir, interior glue, 1/2 in. thick)	1.9	
Wood, sugar pine		0.4 - 5.4



CONDENSATION

- When air containing moisture cools, some of the moisture is released – it condenses into liquid water
- The temperature at which this occurs is the “dew point”
- Condensation occurs when humid air meets cold surfaces such as walls, chilled water lines, even insulation, above or near pools



Figure 4

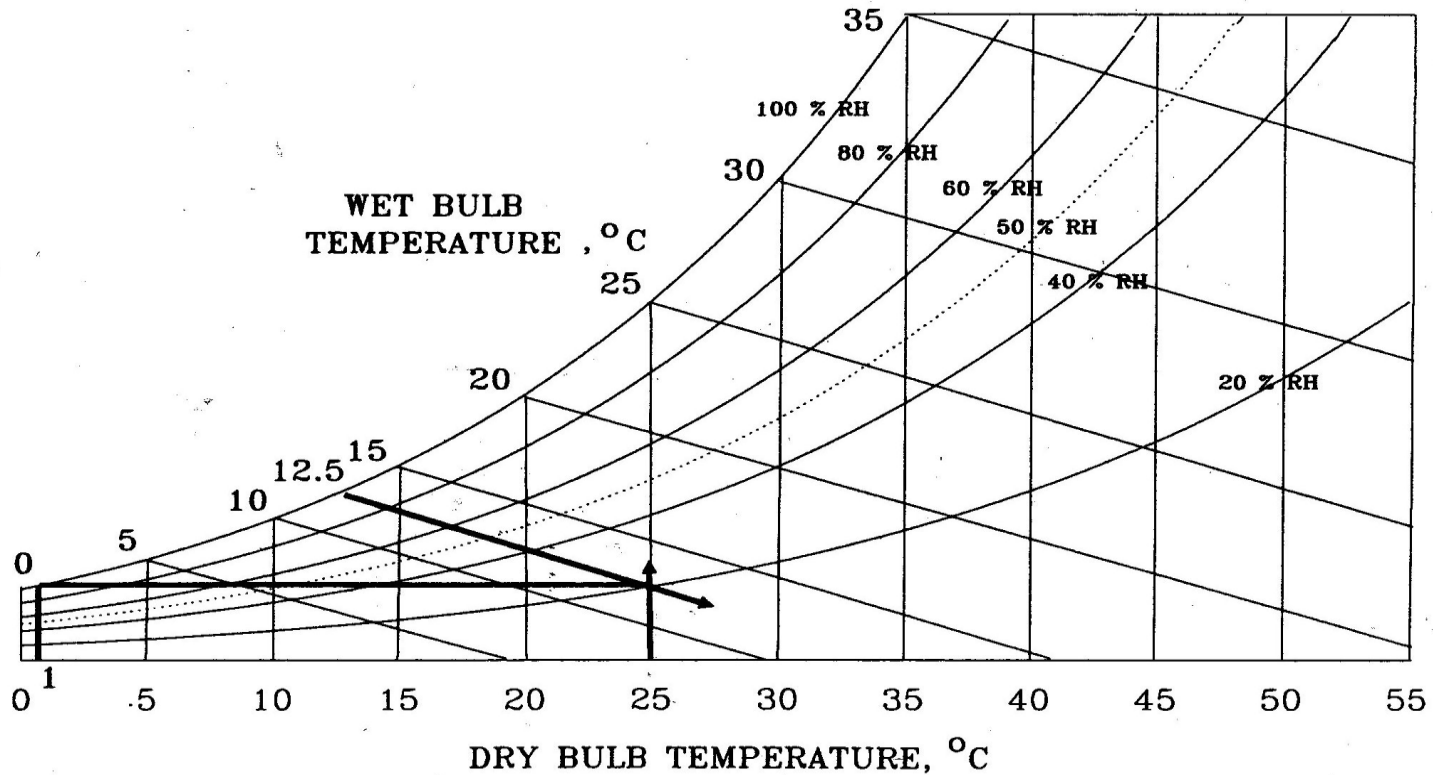


FIG. A4—Calculation of relative humidity and dew point temperature from psychrometric measurements.



Figure 3

The NRCA Roofing and Waterproofing Manual—Fifth Edition

APPENDIX 4: PSYCHROMETRIC TABLE

Dew-Point Temperature (°F)															
Relative Humidity	Design Dry Bulb (Interior) Temperature (°F)														
	32°F	35°F	40°F	45°F	50°F	55°F	60°F	65°F	70°F	75°F	80°F	85°F	90°F	95°F	100°F
100%	32	35	40	45	50	55	60	65	70	75	80	85	90	95	100
90%	30	33	37	42	47	52	57	62	67	72	77	82	87	92	97
80%	27	30	34	39	44	49	54	58	64	68	73	78	83	88	93
70%	24	27	31	36	40	45	50	55	60	64	69	74	79	84	88
60%	20	24	28	32	36	41	46	51	55	60	65	69	74	79	83
50%	16	20	24	28	33	36	41	46	50	55	60	64	69	73	78
40%	12	15	18	23	27	31	35	40	45	49	53	58	62	67	71
30%	8	10	14	16	21	25	29	33	37	42	46	50	54	59	62
20%	6	7	8	9	13	16	20	24	28	31	35	40	43	48	52
10%	4	4	5	5	6	8	9	10	13	17	20	24	27	30	34

Adapted from ASHRAE Psychrometric Chart, 1993 ASHRAE Fundamentals Handbook.



WATER VAPOR PRESSURE

- Gases, including water vapor, exert pressure.
- The atmospheric pressure created by water vapor in the air.
- Water vapor will flow from the place of higher vapor pressure, to the place where the vapor pressure is lower
- Higher temperature = higher energy
- Pressure difference in building assemblies occurs in two typical conditions:
 - Cooling Climate, where exterior temperature and humidity is high
 - Warming Climate, where interior temperature and humidity is higher than exterior



Figure 1

Cooling Climate

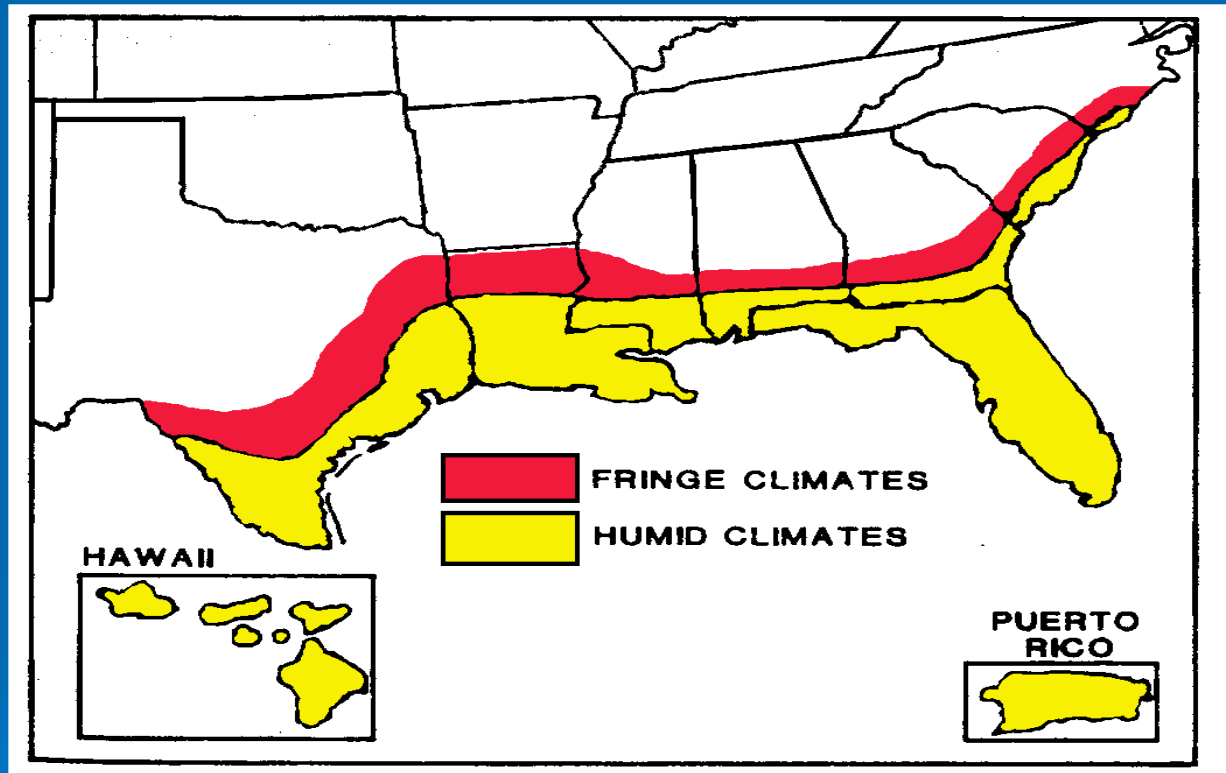
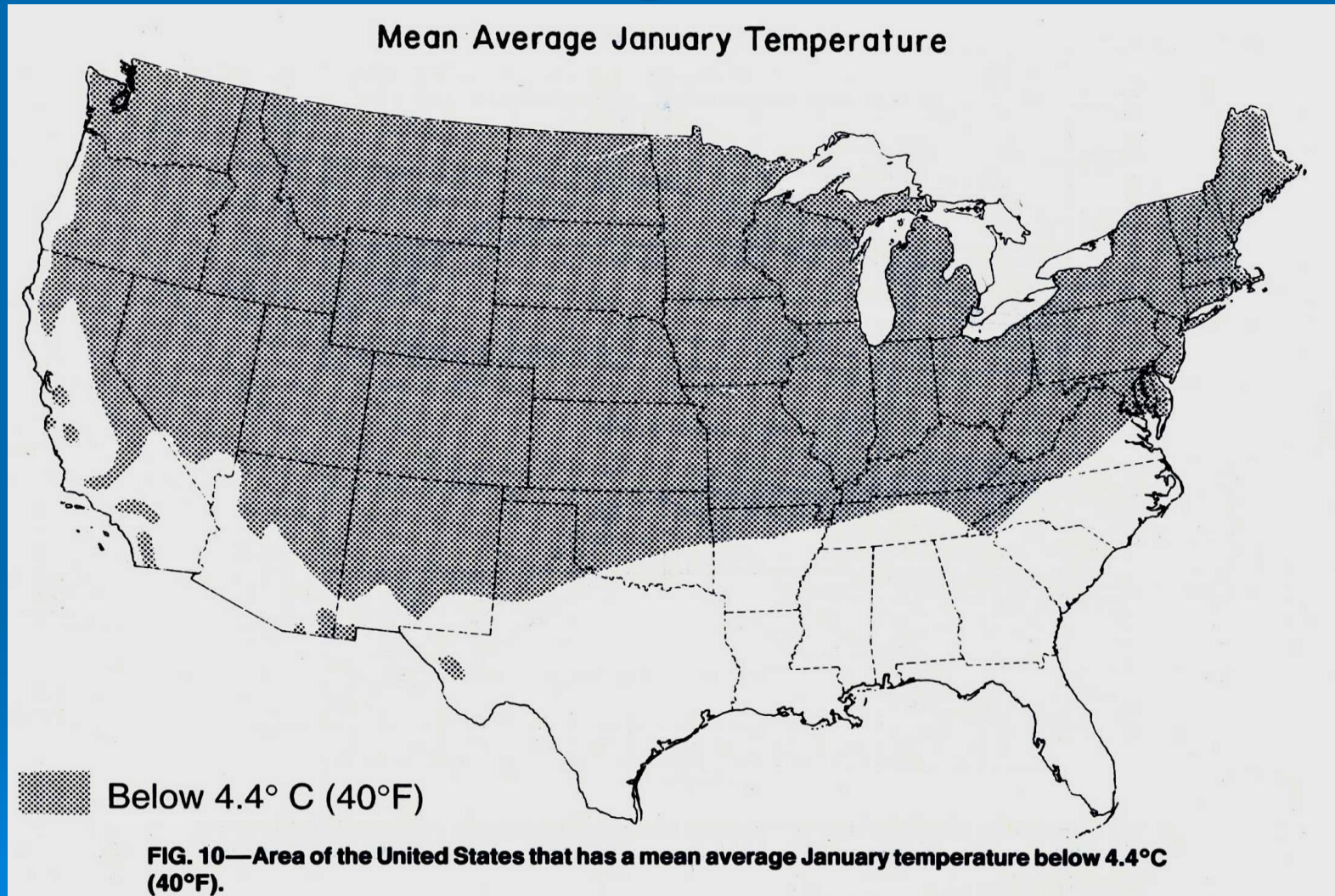


Figure 2

Warming Climate



Case Study #1 (COOLING CLIMATE) EXAMPLE OF CONDENSATION IN HOTEL PARTY WALL



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Case Study # 1

- Honolulu, Hawaii hotel
- Air leakage through failed sealant joint between lanai door and exterior wall
- Condensation between hotel party walls
- Calculate how much condensation (gallons) of water accumulates on the wall in 1 week time span.



Condensation between hotel party walls



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**Moisture intrusion through
air leakage at exterior side
of party wall**



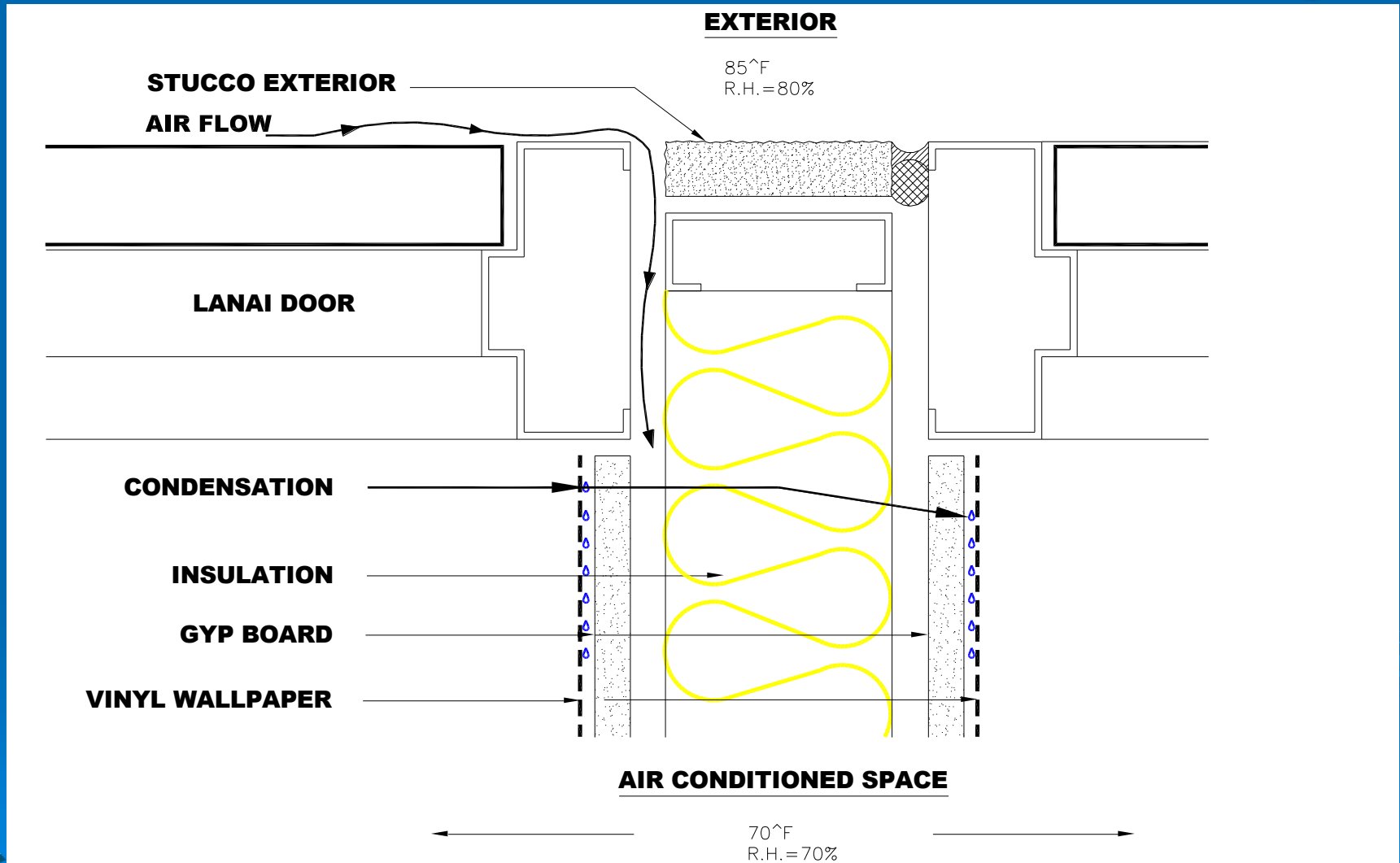
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Case Study # 1, Hawaii Hotel interior wall, condensation due to air leakage





Vinyl
wallpaper



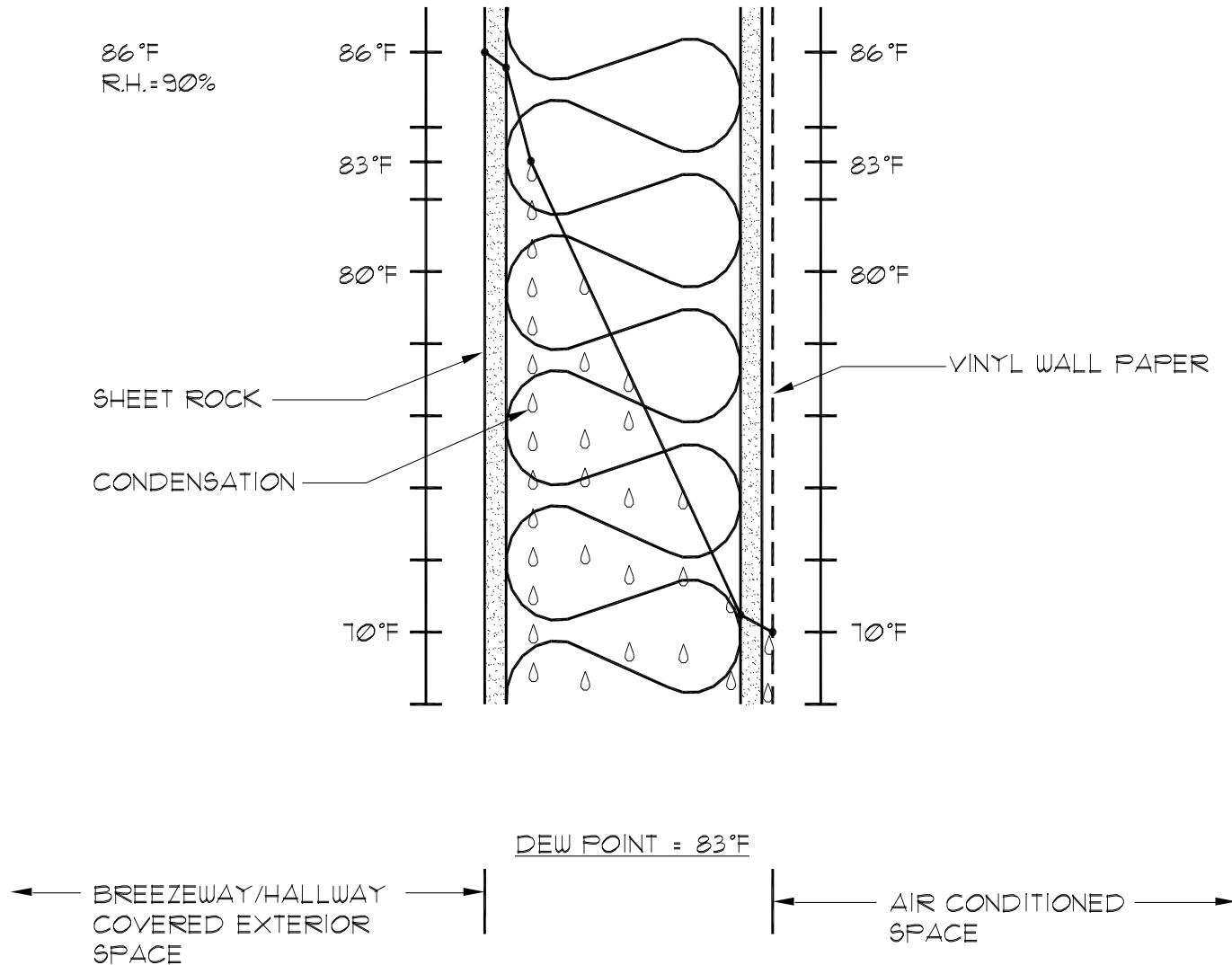
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WHERE CONDENSATION OCCURS



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Case Study # 1: Moisture trapped in a shared wall cavity.

Gaps near an exterior door allow warm humid air to flow into a wall cavity in a Hawaii Hotel (see Figure 10). The affected wall area 10'x8'. Outside temperature and relative humidity are 85F and 80% respectively. The inside temperature and relative humidity are 70F and 70% respectively. Assume condensation forms at the back side of the low perm vinyl wallpaper coating. How much water can collect over a 1 week period?



Vapor Transmission Equation

$$VT = A \times T \times \Delta P \times \text{permeance}$$

VT = Water vapor transmission in grains
(1lb=7000 grains)

A = Area (square feet)

T = Time (hours)

ΔP = Pressure difference (in. Hg)

Perms = Perm rating (grains/ft²/hr/in. Hg)



Case Study # 1: Moisture trapped in a shared wall cavity.

Step 1: Area = 10'x8' = 80 ft²

Step 2: Time = 1 week = 168 hrs

Step 3: Pressure difference – go to figure 9. At 85F, the saturated vapor pressure is 1.213 in.Hg. At 70F, the saturated vapor pressure is 0.7392 in.Hg. Multiply each of the saturated vapor pressures by their relative humidity. The pressure difference is $\Delta P = (1.213 \times 0.80) - (0.7392 \times 0.70) = 0.4523$ in.Hg



Figure 9 – Vapor Pressures for Saturated Air

°F	in Hg	°F	in Hg	°F	in Hg	°F	in Hg
-65	.0007	15	.0806	43	.2782	71	.7648
-60	.0010	16	.0847	44	.2891	72	.7912
-55	.0014	17	.0889	45	.3004	73	.8183
-50	.0020	18	.0933	46	.3120	74	.8462
-45	.0028	19	.0979	47	.3240	75	.8750
-40	.0039	20	.1028	48	.3364	76	.9046
-35	.0052	21	.1078	49	.3493	77	.9352
-30	.0070	22	.1131	50	.3626	78	.9666
-25	.0094	23	.1186	51	.3764	79	.9989
-20	.0126	24	.1243	52	.3906	80	1.032
-15	.0167	25	.1303	53	.4052	81	1.066
-10	.0220	26	.1366	54	.4203	82	1.102
-5	.0289	27	.1432	55	.4359	83	1.138
0	.0377	28	.1500	56	.4520	84	1.175
1	.0397	29	.1571	57	.4686	85	1.213
2	.0419	30	.1645	58	.4858	86	1.253
3	.0441	31	.1723	59	.5035	87	1.293
4	.0464	32	.1803	60	.5218	88	1.335
5	.0488	33	.1878	61	.5407	89	1.378
6	.0514	34	.1955	62	.5601	90	1.422
7	.0542	35	.2035	63	.5802	91	1.467
8	.0570	36	.2118	64	.6009	92	1.513
9	.0599	37	.2203	65	.6222	93	1.561
10	.0629	38	.2292	66	.6442	94	1.610
11	.0661	39	.2383	67	.6669	95	1.660
12	.0695	40	.2478	68	.6903	96	1.712
13	.0730	41	.2576	69	.7144	97	1.765
14	.0767	42	.2677	70	.7392	98	1.819



Case Study # 2: Conclusion.

Step 4: Effective perm rating. The perm ratings for the materials are as shown in FIG 5:

Gypsum Board = 50

Step 5: Plug values into the vapor transmission equation:

$$\begin{aligned} VT &= 80 \text{ ft}^2 \times 168 \text{ hr} \times 0.4523 \text{ in.Hg} \times 50 \text{ perm} \\ &= 304,389 \text{ grains of water} \\ &= 43.5 \text{ pounds of water} \\ &= \mathbf{5.24 \text{ gallons of water (in 1 week)}} \end{aligned}$$



Exterior Cement Plaster

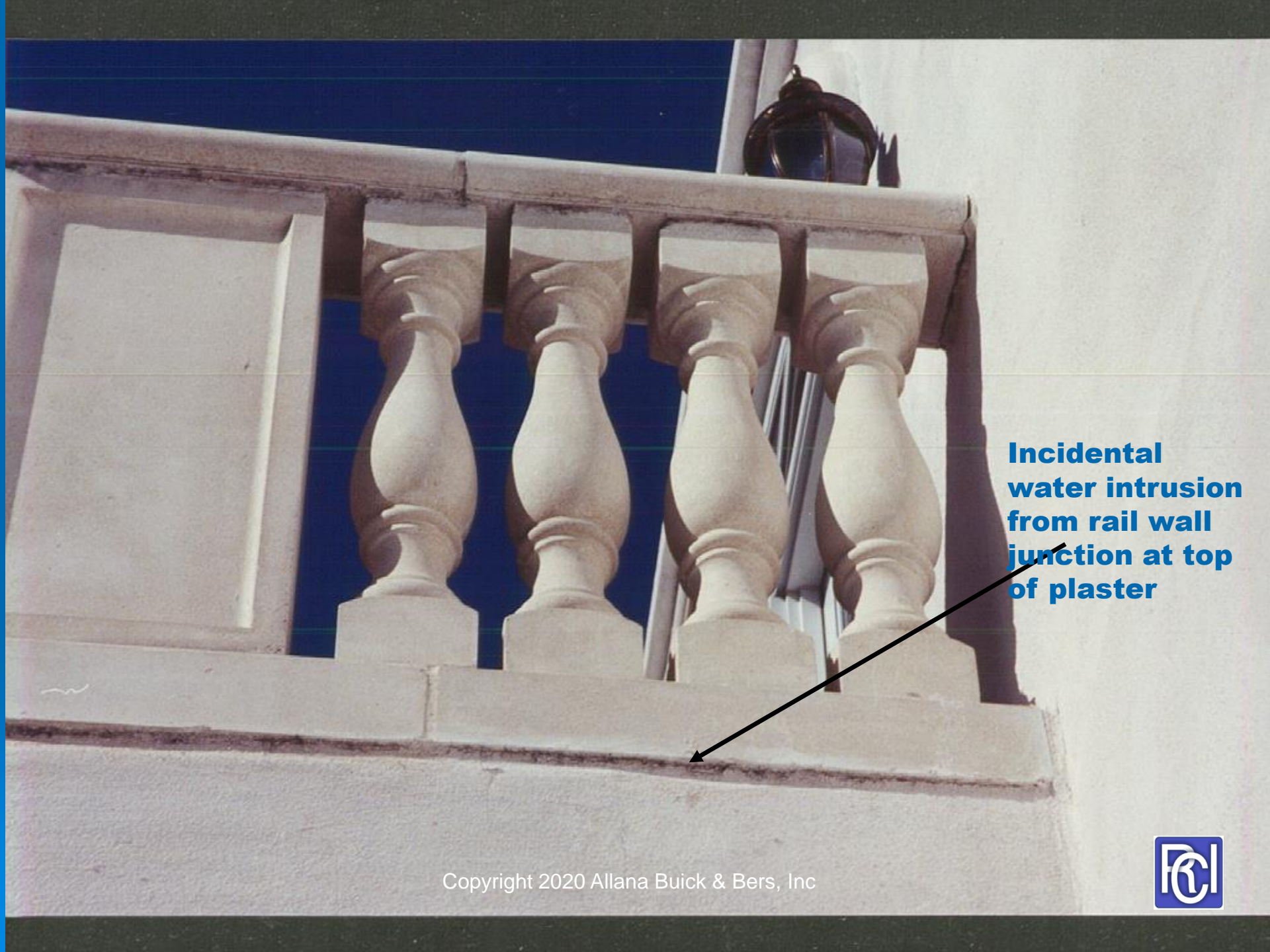
- **Drainable Wall System (not pressure equalized)**
- **Common Modes of Water Intrusion**
- **Mechanism for water weeping and drying**
- **Stucco Design Philosophy**
 - **Design as a Barrier Wall**
 - **Design as a conventional Drainable Wall**

**Incidental water intrusion
happens behind stucco**



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**Incidental
water intrusion
from rail wall
junction at top
of plaster**

Minor stains from rail wall junction



This innocent looking Incidental water caused a lot of damage!



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**Stucco leak from
top of rail wall**

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WINDOWS ISSUES

**Cracks and
sealant failure
around window**



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Case Study # 2, Stucco Leak in wall. Study of slow diffusion



Few visible signs of distress



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**Relatively benign looking
vinyl wall paper**



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**Removal of a small area
displayed evidence of
some real problems**

Case Study # 2, Slow diffusion due to vapor barrier on the inside face of wall



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Mold and rot in the wall cavity



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Case Study # 2, slow diffusion in wall can cause a lot of damage from leaks



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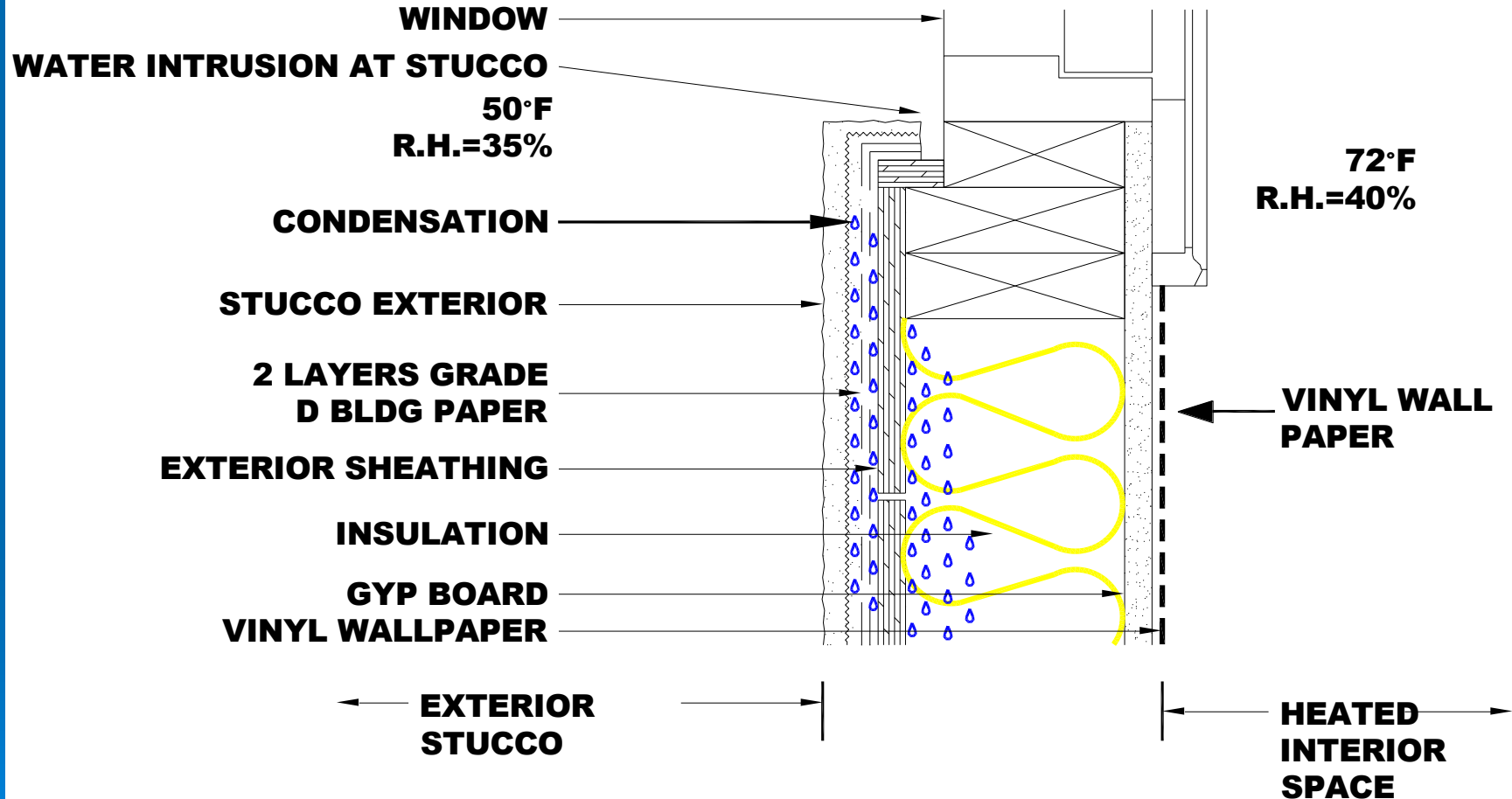
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Case Study # 2: Moisture trapped in different layers of a wall assembly, how long before it dries?.

During the rainy season, water collects in a wall due to a window leak in the locations shown (see Figure 13). The affected area is 100 ft². Outside temperature and relative humidity are 50F and 35% respectively. The inside temperature and relative humidity are 72F and 40% respectively. Under these conditions, moisture will flow from inside to outside. How much time will it take for the water to leave the assembly in each of the locations? Each location has 1 gallon of water intrusion.



Case Study # 2, Diffusion. How long does it take for water to dry? (Fig 13)



Example: Moisture trapped in a wall from a window leak.

Step 1: Area = 100 ft²

Step 2: Pressure differences – go to figure 9. At 72F, the saturated vapor pressure is 0.7912 in.Hg. At 50F, the saturated vapor pressure is 0.3636 in.Hg. Multiply each of the saturated vapor pressures by their relative humidity. The pressure difference is $\Delta P = (0.7912 \times 0.40) - (0.3636 \times 0.35) = 0.1896$ in.Hg



Example: Moisture trapped in a wall from a window leak.

Step 3: Pressure distribution. The pressure at each material in the wall can be determined from the following formula:

$$\Delta P_{\text{material}} = (Z_{\text{material}}/Z_{\text{wall}}) \times \Delta P_{\text{wall}}$$

$\Delta P_{\text{material}}$ = Pressure drop at each material

Z_{material} = Inverse permeance of each material

Z_{wall} = Effective inverse permeance of system

ΔP_{wall} = Total pressure change from step 2



Example: Moisture trapped in a wall from a window leak.

The permeance values for the materials in the wall are as follows:

Stucco over metal lath = 15

2 layers 60 min. building paper = 5 ea.

OSB sheathing = 2

Insulation = 30

Gypsum board = 50

Vinyl wallpaper = 1

These values each need to be reciprocated to obtain Z_{material} for each material.



Example: Moisture trapped in a wall from a window leak.

The effective permeance, Z_{wall} , is:

$$\begin{aligned} Z_{\text{wall}} &= 1/15 + 1/5 + 1/5 + 1/2 + 1/30 + 1/50 + 1/1 \\ &= 2.02 \text{ perm}^{-1} \end{aligned}$$

Now we can determine the pressure drops at each material layer in the wall system using the formula for pressure differential provided earlier:

$$\Delta P_{\text{material}} = (Z_{\text{material}}/Z_{\text{wall}}) \times \Delta P_{\text{wall}}$$



Example: Moisture trapped in a stucco wall from a window leak.

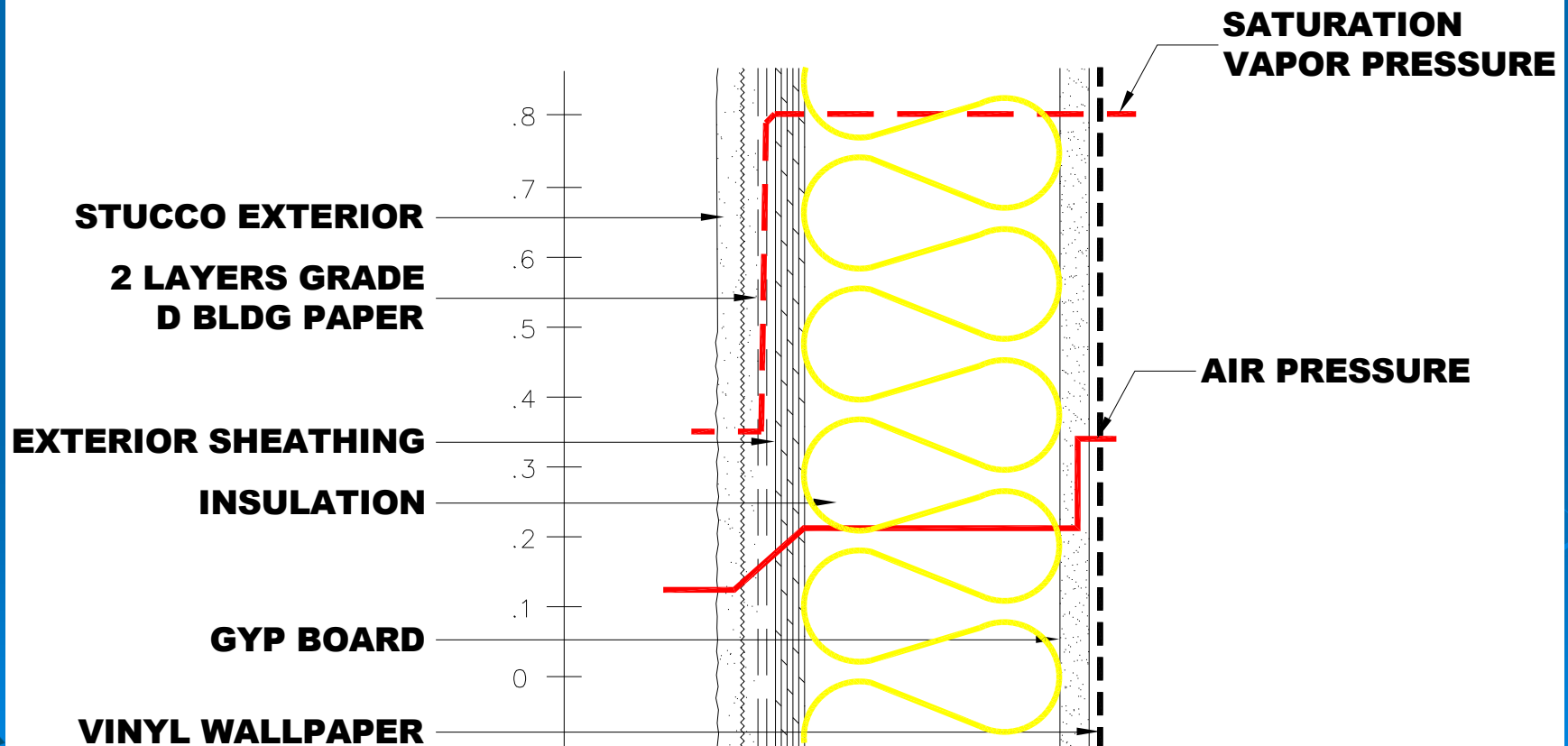
The pressure distribution in the wall is tabulated:

<u>Material</u>	<u>Pressure Drop</u>	<u>ΔP</u>
		0.3165
Wallpaper	0.09386	0.22264
Gypsum	0.001877	0.22076
Insulation	0.003129	0.21763
OSB	0.046931	0.17070
Paper	0.0187723	0.15193
Paper	0.0187723	0.13315
Stucco	0.006257	0.12690



Air and Saturation Pressure gradient: Figure 14

PRESSURE & TEMPERATURE DISTRIBUTION



Case Study # 2: Moisture trapped in different layers in the wall

Step 4: Determine the time required for diffusion at each location. Rearrange the Vapor Transmission Equation to isolate the time variable T:

$$VT = A \times T \times \Delta P \times \text{permeance}$$

$$T = VT / (A \times \Delta P \times \text{permeance})$$

Continue by applying the formula to each of the “wet” locations.



Case Study # 2: How long does it take for 0.1 Gallon of water to dry if trapped between paper & stucco?

Location 1- Moisture over the building paper:

From the pressure distribution,

$$\Delta P = 0.13315 - 0.12690 = 0.0066 \text{ in. Hg}$$

The effective Z value only takes into account the stucco since moisture will be driven out from inside the building/wall assembly.

$$Z = 1/15 \text{ perm}^{-1}$$

$$\text{Permeance} = 15 \text{ perm}$$



Case Study # 2: How long does it take for 0.1 Gallon of water to dry if trapped between paper & stucco?

Therefore, converting gallons into grains (1/10 gallon = 5809 grains):

$$\begin{aligned} T &= 5,809 \text{ gr} / (100\text{ft}^2 \times 0.0066 \text{ in.Hg} \times 15 \text{ perm}) \\ &= 587 \text{ hours} \\ &= 24 \text{ days} \end{aligned}$$



Similarly: How long does it take for 0.1
Gallon of water to dry if trapped between
OSB and paper?

$$\begin{aligned} T &= 5,809 \text{ gr}/(100\text{ft}^2 \times 0.0438 \text{ in.Hg} \times 2.143 \text{ perm}) \\ &= 619 \text{ hours} \\ &= 26 \text{ days} \end{aligned}$$



Case Study # 2: How long does it take for 1 Gallon of water to dry if trapped between Insulation and OSB?

Location 3- Over the insulation:

From the pressure distribution,

$$\Delta P = 0.21763 - 0.12690 = 0.0907 \text{ in. Hg}$$

Find the effective Z value:

$$Z = 1/15 + 1/5 + 1/5 + 1/2 = 0.96667 \text{ perm}^{-1}$$

$$\text{Permeance} = 1/Z = 1.034 \text{ perm}$$



Case Study # 2: How long does it take for 1 Gallon of water to dry if trapped between Insulation and OSB?.

$$\begin{aligned} T &= 58094 \text{ gr}/(100\text{ft}^2 \times 0.0907 \text{ in.Hg} \times 1.034 \text{ perm}) \\ &= 6190 \text{ hours} \\ &= 264 \text{ days} \end{aligned}$$

The rate of diffusion changed due to plywood/OSB which is a vapor retarder.



STUCCO LESSONS

- ❑ Old stucco system with just Grade “D” building paper and no consideration for managing excess water does not work.
- ❑ Acceptable tolerance for incidental water intrusion needs to be greatly reduced.
- ❑ Design should consider building cement plaster more as a “barrier” system.
- ❑ Alternatively, provide a layer of “water management” system such as rain screen or pressure equalized behind the cement plaster finish.



LESSONS LEARNT FROM INCIDENTIAL WATER IN STUCCO

- Construction methods have significantly changed. Buildings are built much more air tight.
- A lot of attention has been given to air barriers to control movement of moisture laden air.
- Air barriers also impede the “drying” out effect in walls. Diffusion is not enough to dry out walls.
- Construction labor is less skilled today



LESSONS LEARNT FROM INCIDENTIAL WATER IN STUCCO

➤ When designing wall assemblies, consider the following:

- Be less reliant on building paper and “permeable” coatings.
- Design walls to be more “barrier” assemblies or as rain screen assemblies.
- Ventilate whenever possible.
- Consider vapor retarders in all climates
- Limit use of vinyl wall paper in exterior wall assemblies



Case Study # 2

EIFS Bull Nose

- EIFS Bull Nose Failure
- Design Issues
- Thermal Modeling
- Lesson Learned

Case Study # 2, EIFS Bull Nose Failure

EIFS Barrier System



CHA-AL05795



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4- Story Office Building
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Rather Large EIFS Bull Nose



CHA-AL04351



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Patterns of Cracking in Bull Nose

- There were two distinct pattern of cracking in the bull nose:
 - Horizontal cracks; always located between the flat and curved parts of the bull nose, on top or bottom of the bull nose. Horizontal cracks also located in the center of the bull nose curved shape.
 - Vertical cracks; Randomly located throughout the building and almost always present at the inside corner, at a jog in the exterior wall.
 - Few other cracks fell outside of this pattern where in the same locations there were both vertical and horizontal cracks



Vertical Crack in the Field



CHA-AL03186



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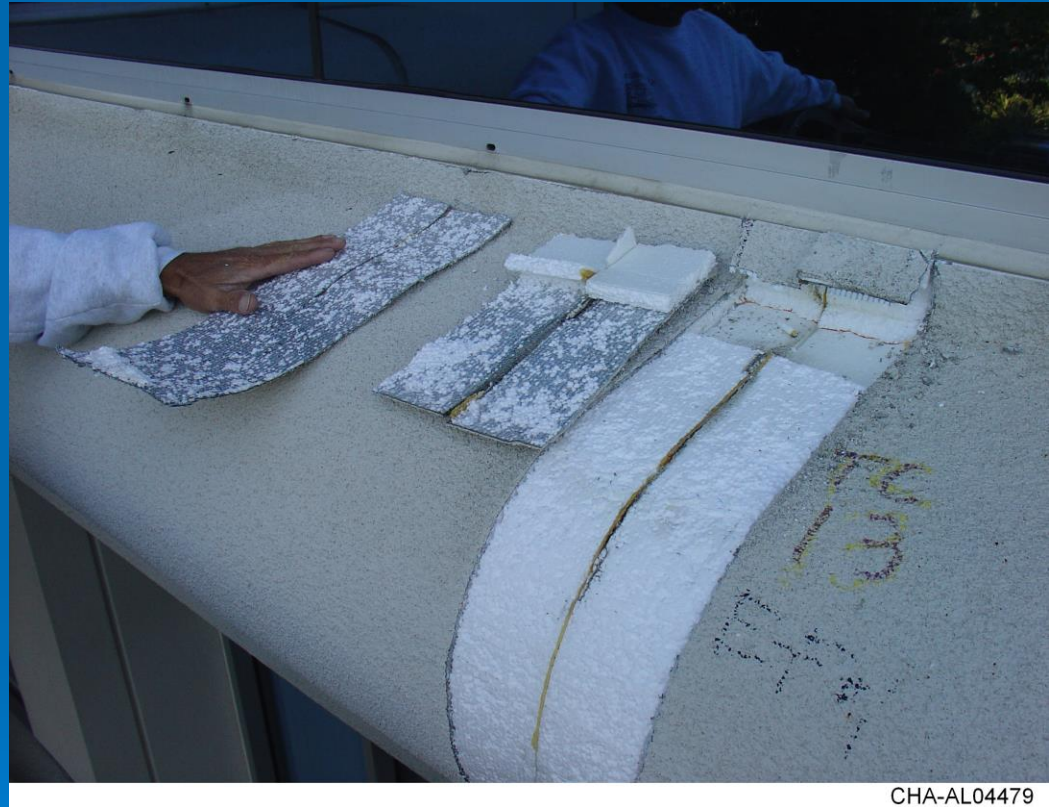
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Reasons for Vertical Cracks

- Generally, vertical cracks were caused by “gaps” in EPS insulation. Gaps create areas where the cementitious base coat collects and creates a discontinuity for thermal movement, causing a split
- In some cases, vertical cracks resulted due to lack of mesh embedment



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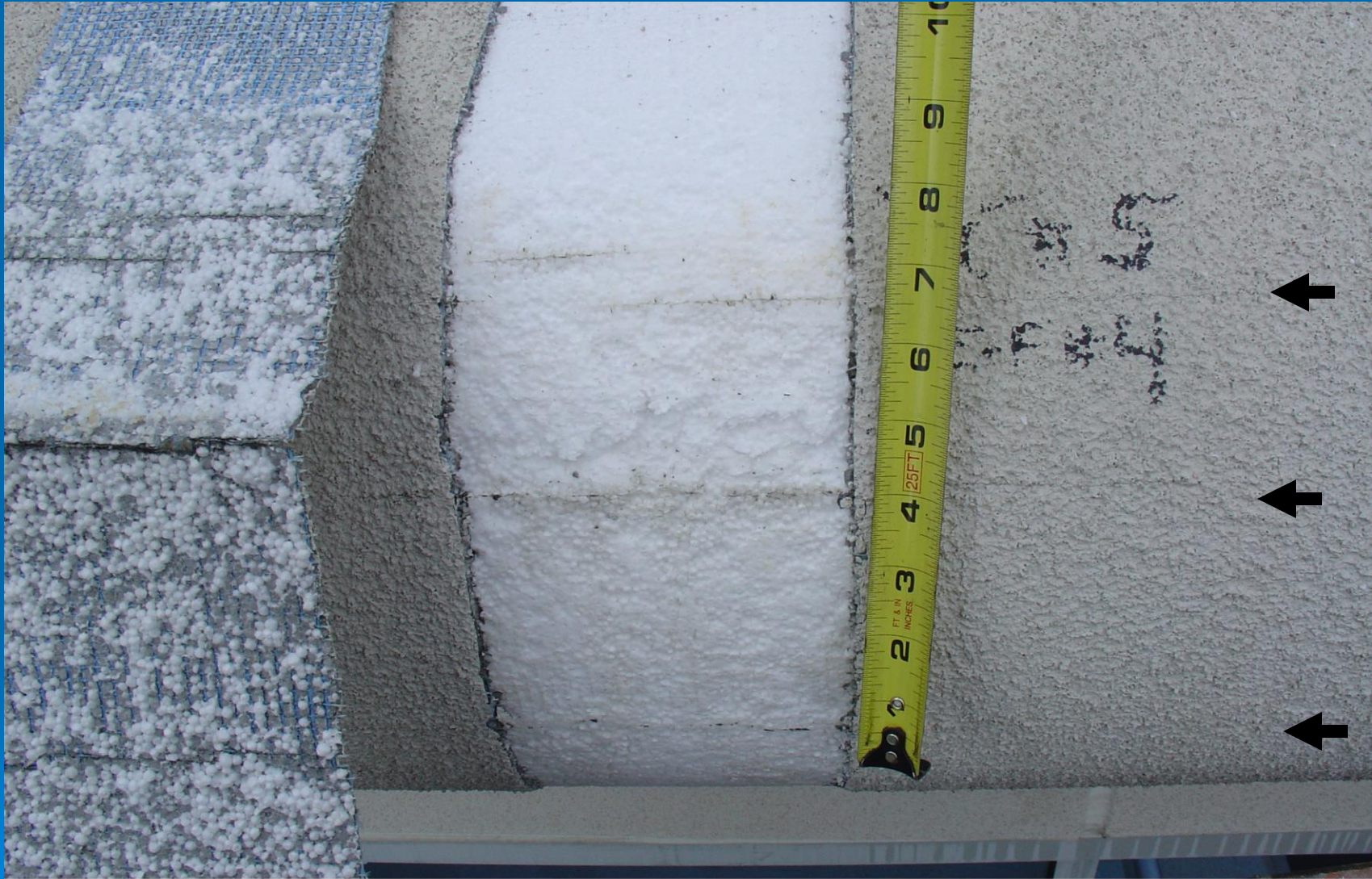
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Horizontal Crack Pattern was Peculiar



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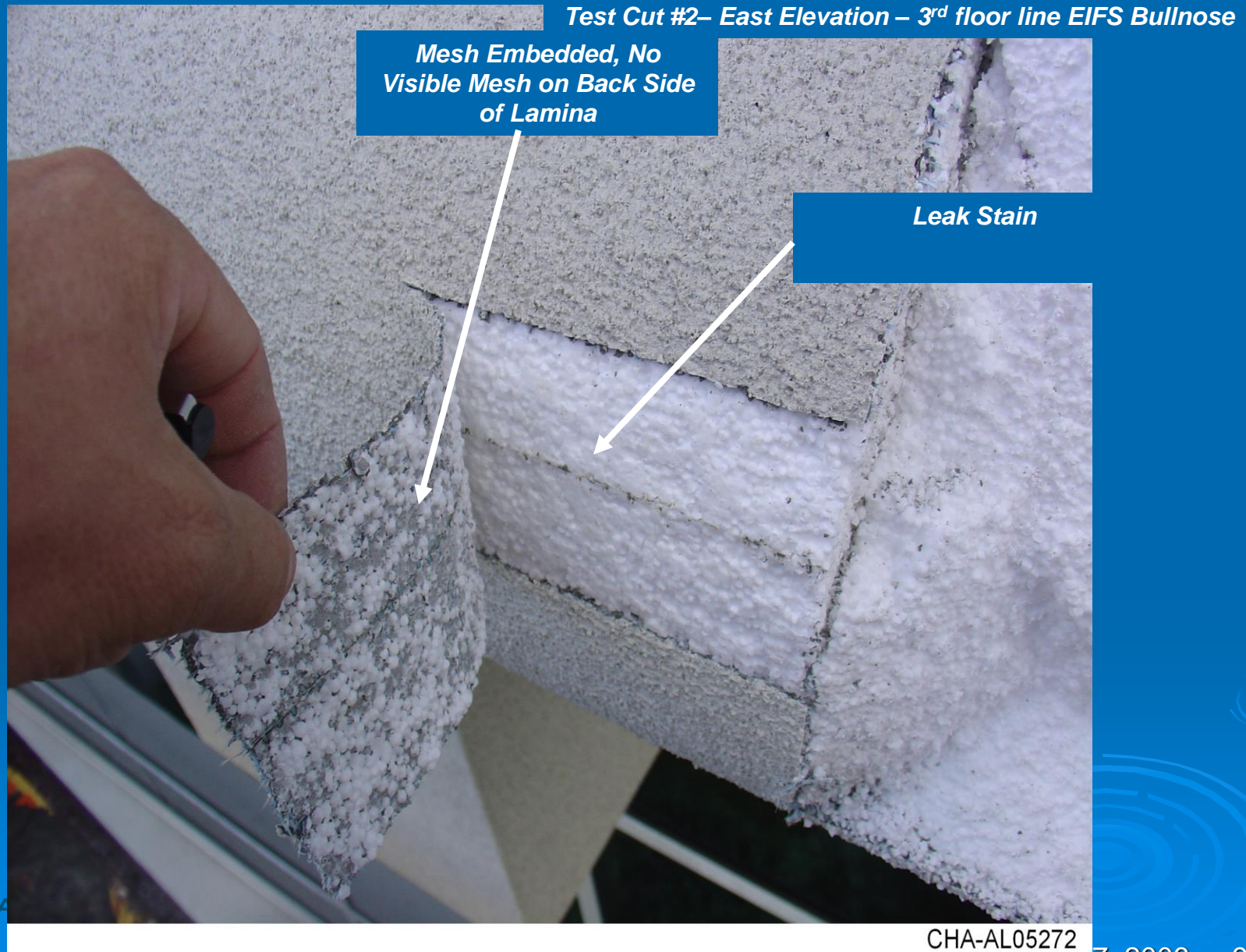
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DESTRUCTIVE TESTING



Travel Path for Water Leak

- EIFS outsulation is a “barrier” system. The 1/16” Cementious skin is the only waterproofing barrier in the system. **CRACKS = WATER INTRUSION & LEAKS**
- Our testing showed that water leaks were occurring from both horizontal (longitudinal) and vertical (perpendicular) cracks in the lamina at the bull noses.
- In case of the horizontal cracks, water traveled between the EIFS lamina and EPS (Expanded Polystyrene Foam), and very slowly moved around the bull nose and leaked to the interior space.



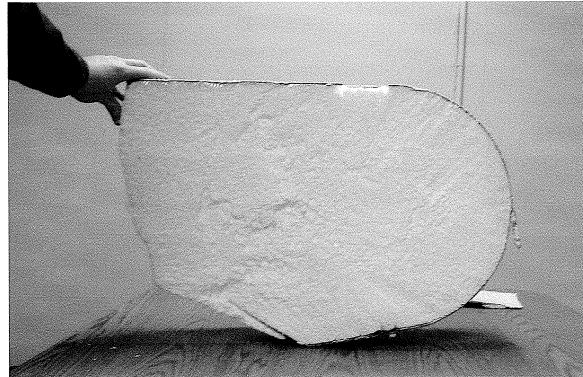
FORENSIC ANALYSIS OF HORIZONTAL CRACKS

- In order to develop a suitable, sustainable, repair for this building, we analyzed the mode of failure.
- The horizontal crack pattern in the EIFS finish at the nose of the bull nose was unusual and distinct.
- Our structural engineering team performed thermal modeling of the bull nose panels to see what kind of forces we could develop.
- We also performed visual analysis of the lamina construction to ascertain the method of construction, rasping of the foam and embedment of mesh in the base coat.
- We looked at the numerous samples that we had gathered to see if there was a pattern.

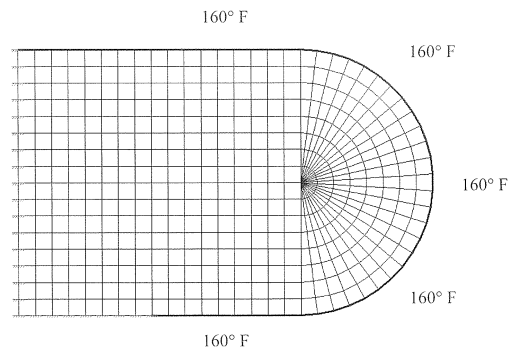


THERMAL ANALYSIS WITH RISA 2D SOFTWARE

5050 Hopyard Preliminary Finite Element Analysis of EIFS bullnose assembly.



5050 Hopyard EIFS bull-nose specimen



2D Finite Element Model of EIFS bull-nose Specimen: Model is subjected to a uniform thermal load of 160 F. Elements are 4 node quadrilaterals and are assigned the

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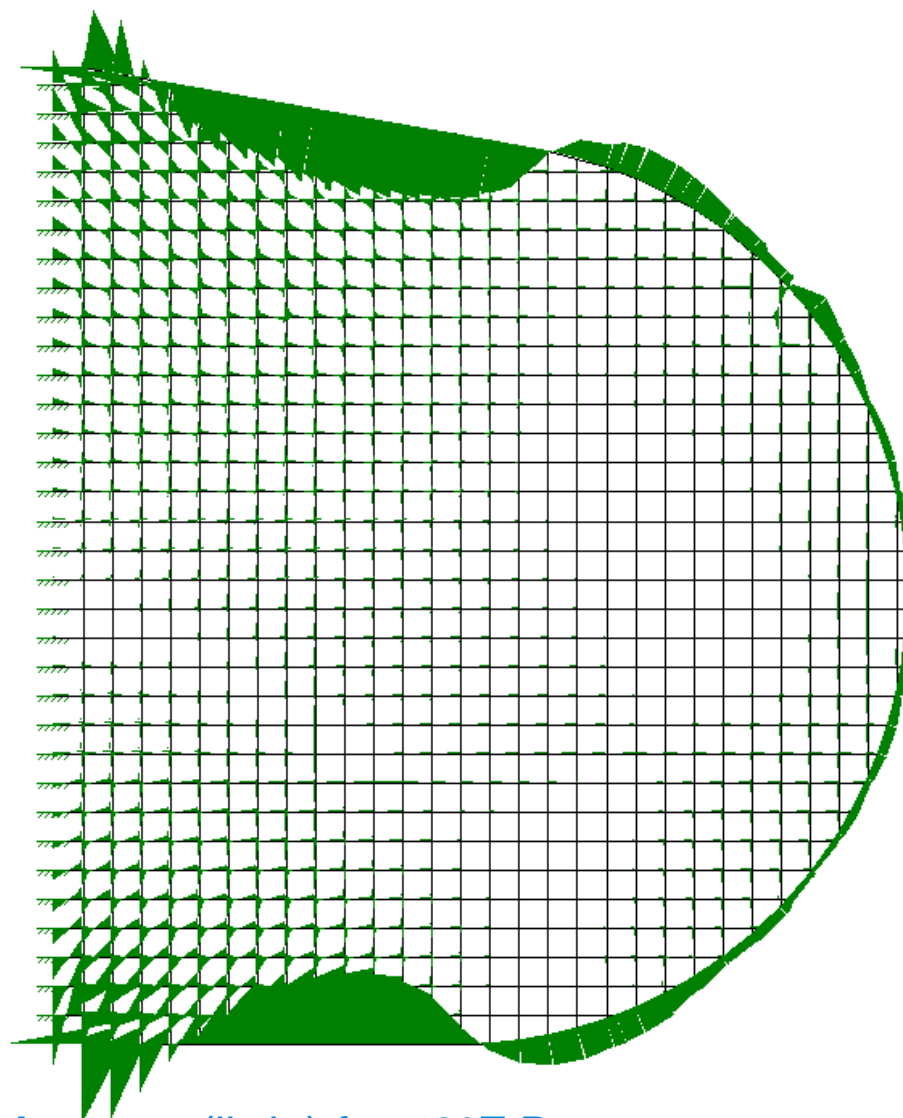


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Moments (lb-in) for 50°F Decrease

Results for LC 1, THERMAL/DISP
Member Bending Moments (lb-in)



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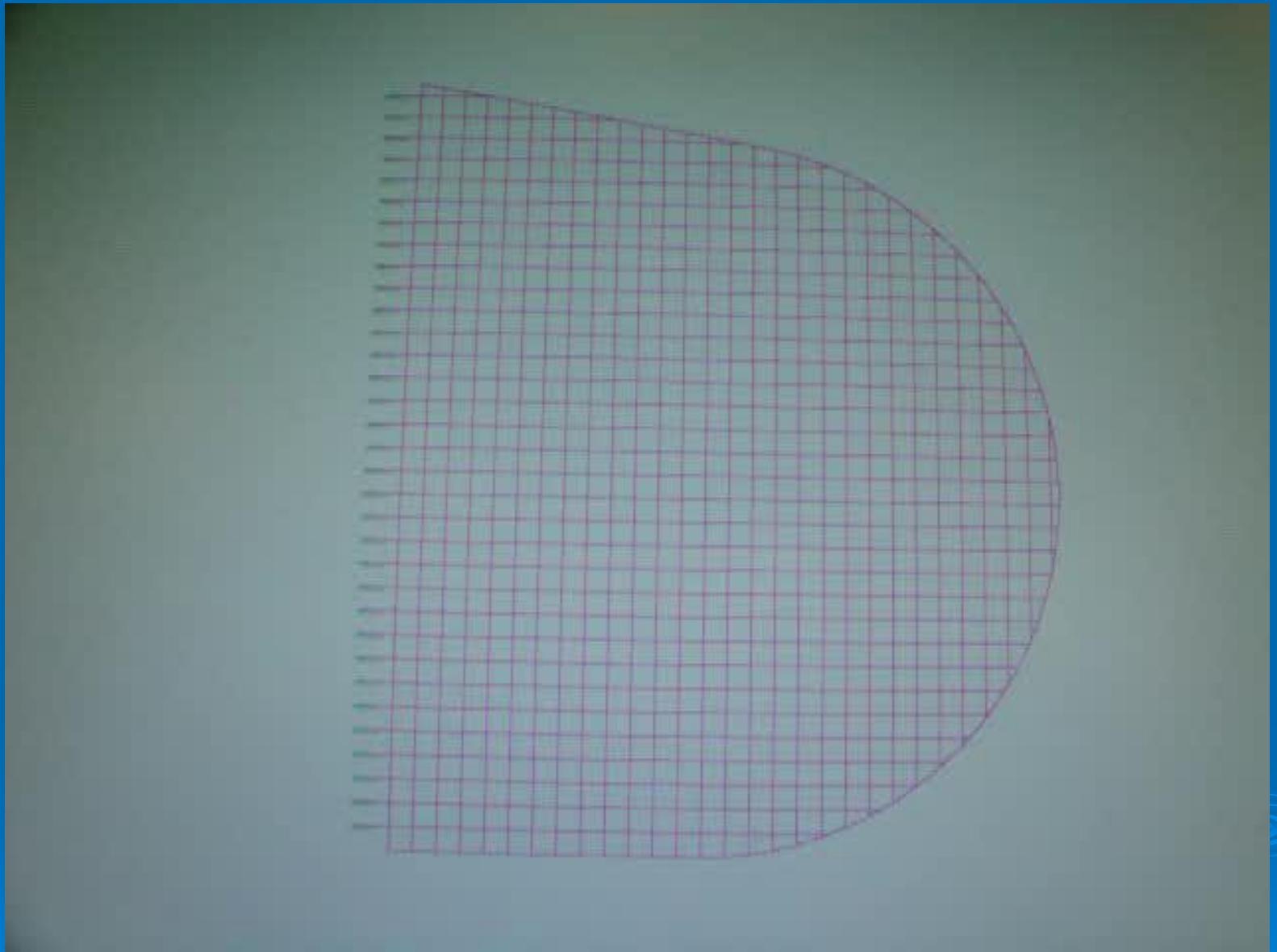


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THERMAL ANALYSIS (For Horizontal Cracks)

- All thermal stresses are concentrated at the shape change area
- Moment reverses at the shape change
- Maximum stress are at the curved portions of the bull nose
- Crack leads to water intrusion, UV and breakdown of the fiberglass mesh causing a split
- The lamina can withstand approximately 150 to 180 pounds of tension per linear inch, and our model shows there's only 4-5 pounds of tension per linear inch, but there is still cracking





50°F Temperature Decrease (100°F to 50°F at 50x magnification)



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FAILURE ANALYSIS EIFS BULL NOSE

- Lamina also undergoes bending, from deformed shape which ultimately caused the failure.
- If EIFS is modeled as a cementitious beam with compressive strength of 3,000 pounds per square inch (“psi”), the modulus of rupture, or “cracking stress” is 411 psi. ABB’s model showed that the maximum bending load of the lamina was .312 lb/in, which translates into 474 psi in the uncracked lamina section. Therefore, the maximum bending stress would exceed the “cracking stress” by 63 psi.



CAUSATION OF HORIZONTAL CRACKS

1. Size and geometry of the bull nose is producing concentrated stress where cracks are occurring.
2. Once lamina is cracked, it allows water intrusion.
3. UV and water degrade the exposed fiberglass mesh at a crack and cause it to split.
4. We explore ways of reducing the mass of the foam, to reduce thermal movement and stresses.



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Thank You
Questions?



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