33RD RCI INTERNATIONAL CONVENTION & TRADE SHOW

Envision the Future

Building Envelope Consulting : Roofing | Waterproofing | Exterior Walls

2018 March 22 - 27

Houston, Texas

Avoiding Condensation in Low-Slope Roofing Assemblies

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Outline of Presentation

- Overview of condensation, dew point, vapor retarder definitions, and vapor retarder placement
- Forensic case study of condensation damage
- Designing low sloped roof assemblies with a vapor retarder
- Designing low sloped roof assemblies with venting

Sources of Water in Roof Assembly

External Moisture Sources

Construction Moisture Sources

Internal Moisture Sources

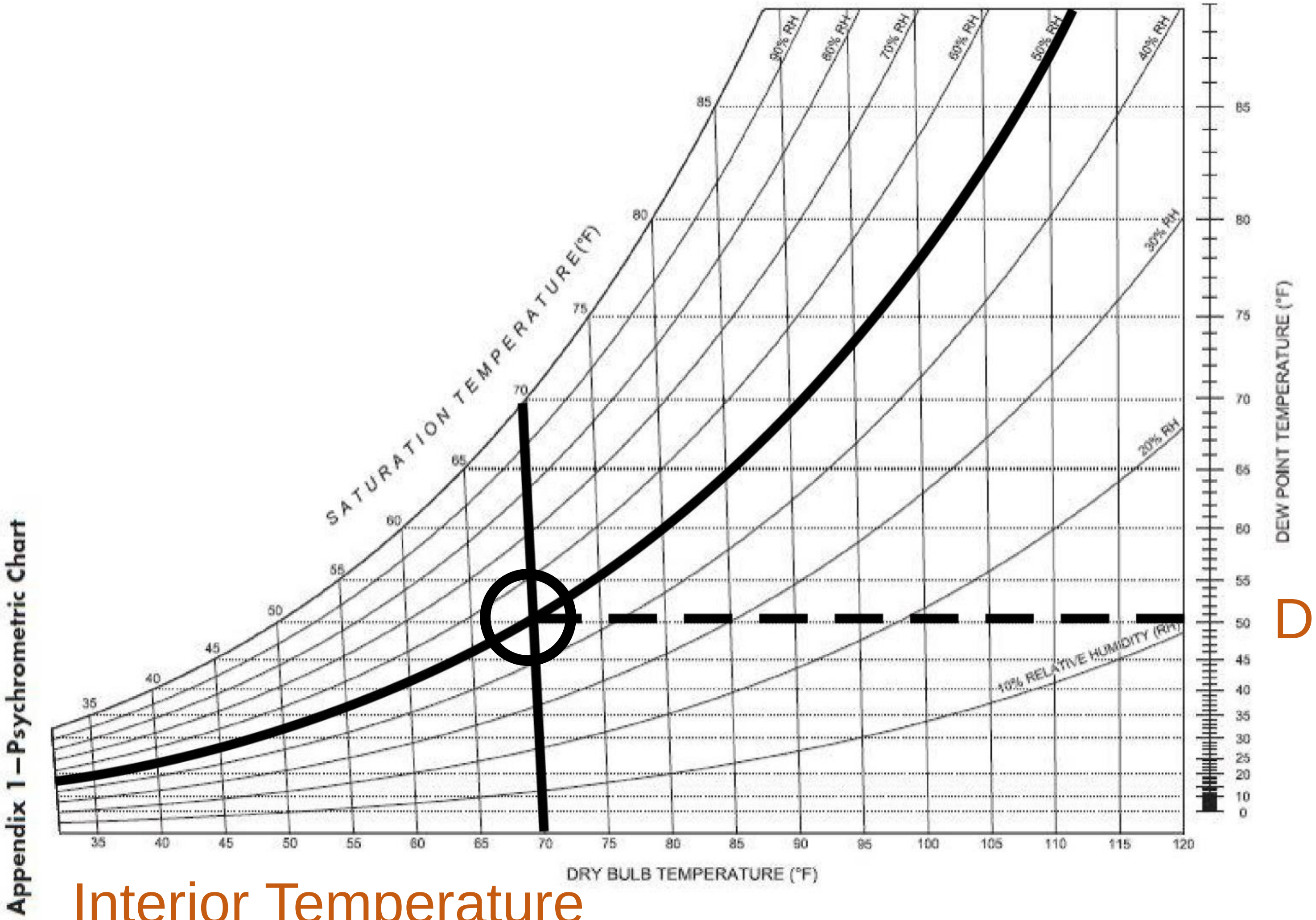
Condensation

- When air containing moisture cools, some of the moisture condenses into liquid water

- The temperature at which this occurs is called the dew point

Psychometric Chart

Interior RH %



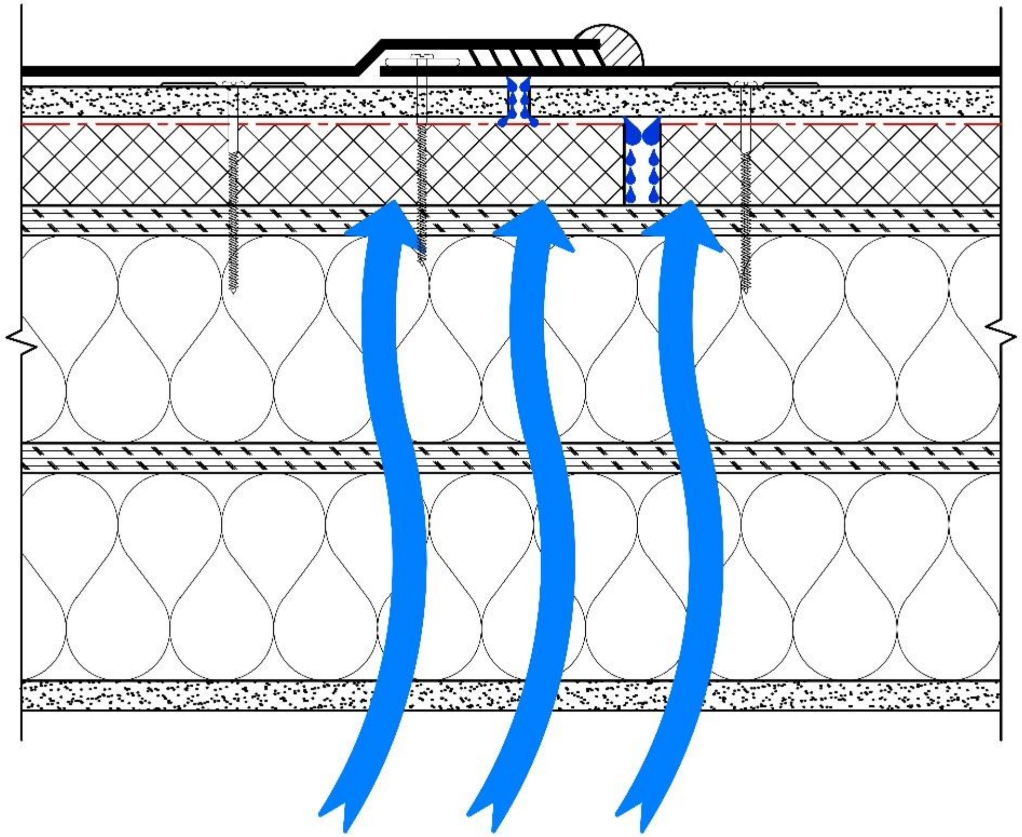
Dew Point

Interior Temperature

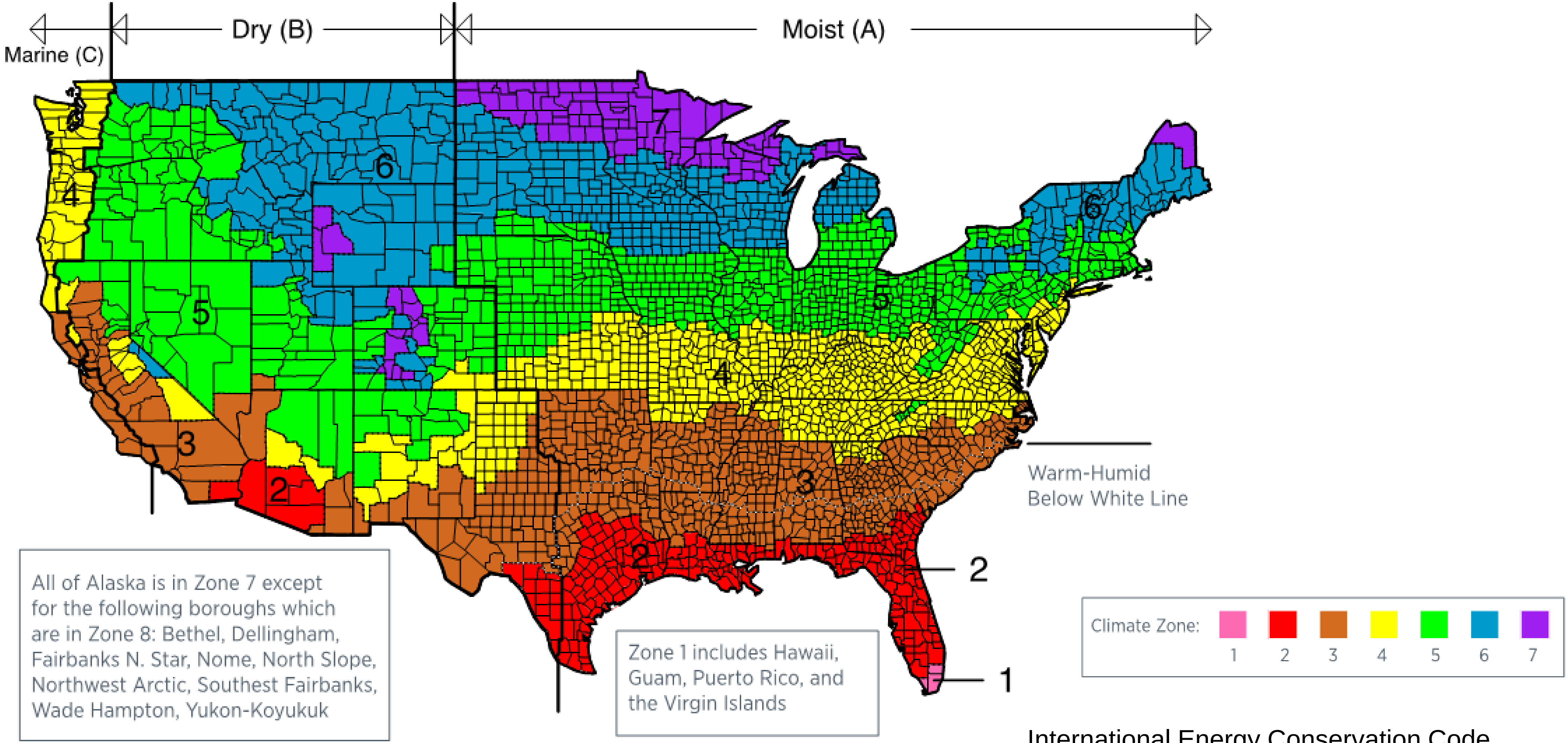
Condensation in Roof Assemblies

- Condensation occurs when warm humid air meets cold surfaces that are below the dew point such as walls, chilled water lines, and undersides of roof assemblies

- Condensation can be avoided by either removing warm humid air by ventilating the assembly or by installing a vapor retarder on the "warm" side

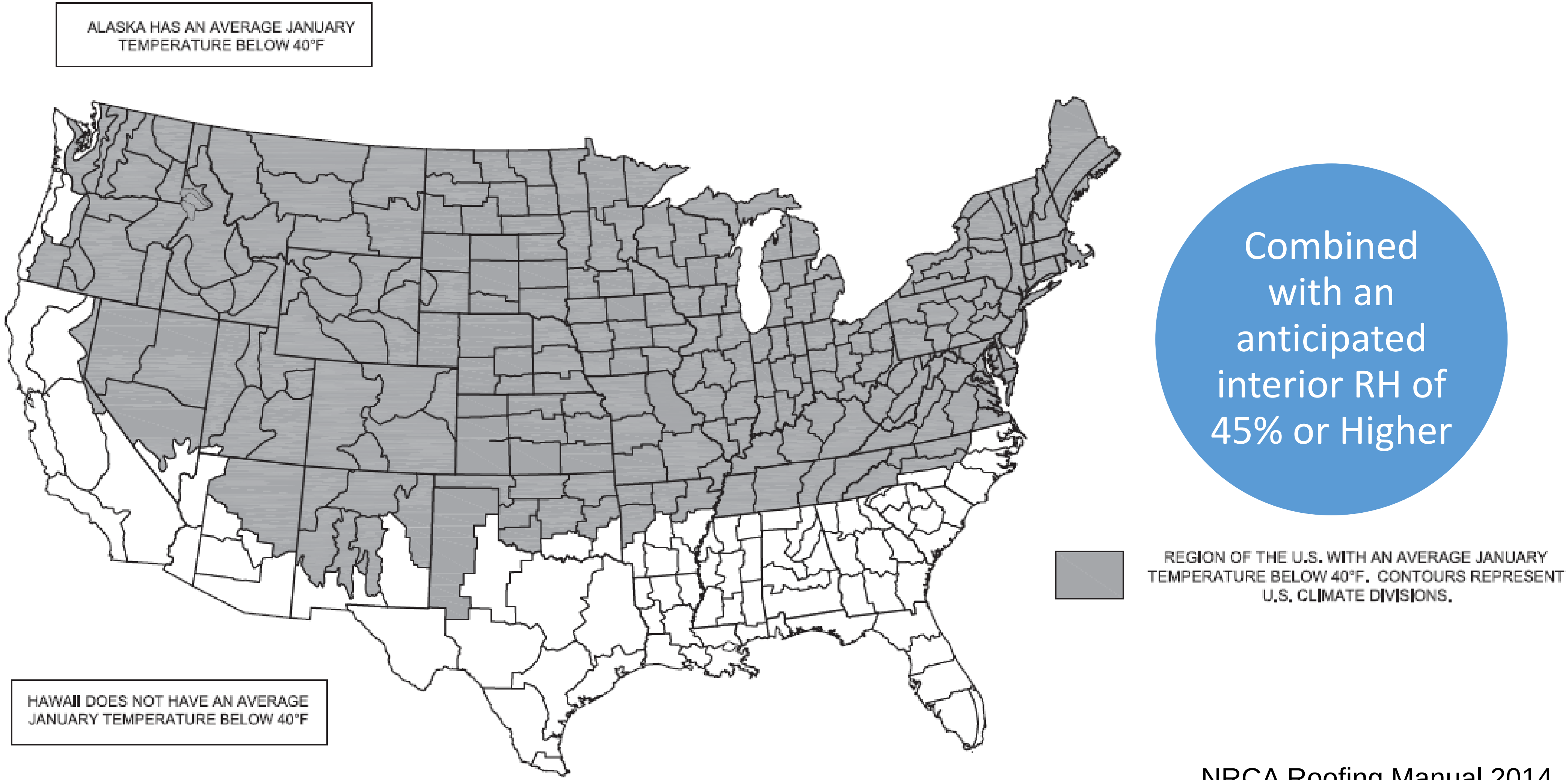


Warm and Cool Climates



International Energy Conservation Code

Warm and Cool Climates



Combined with an anticipated interior RH of 45% or Higher

NRCA Roofing Manual 2014

Self Drying Roofs - California

- California low sloped roof assemblies with wood panel decks have traditionally been installed without a vapor retarder or ventilation
  - The moisture uptake during winter months was overcome by the roofs ability to dry throughout the balance of the year and to not gain moisture over time
- Advent of Energy Star “Cool Roof” compliant roofs have changed how these roofs handle moisture
  - The period of moisture uptake has increased and drying efficiency has been reduced
- We have found new construction and re-roofing projects experiencing condensation and related damage
  - Where designed or installed without vapor retarders or ventilation

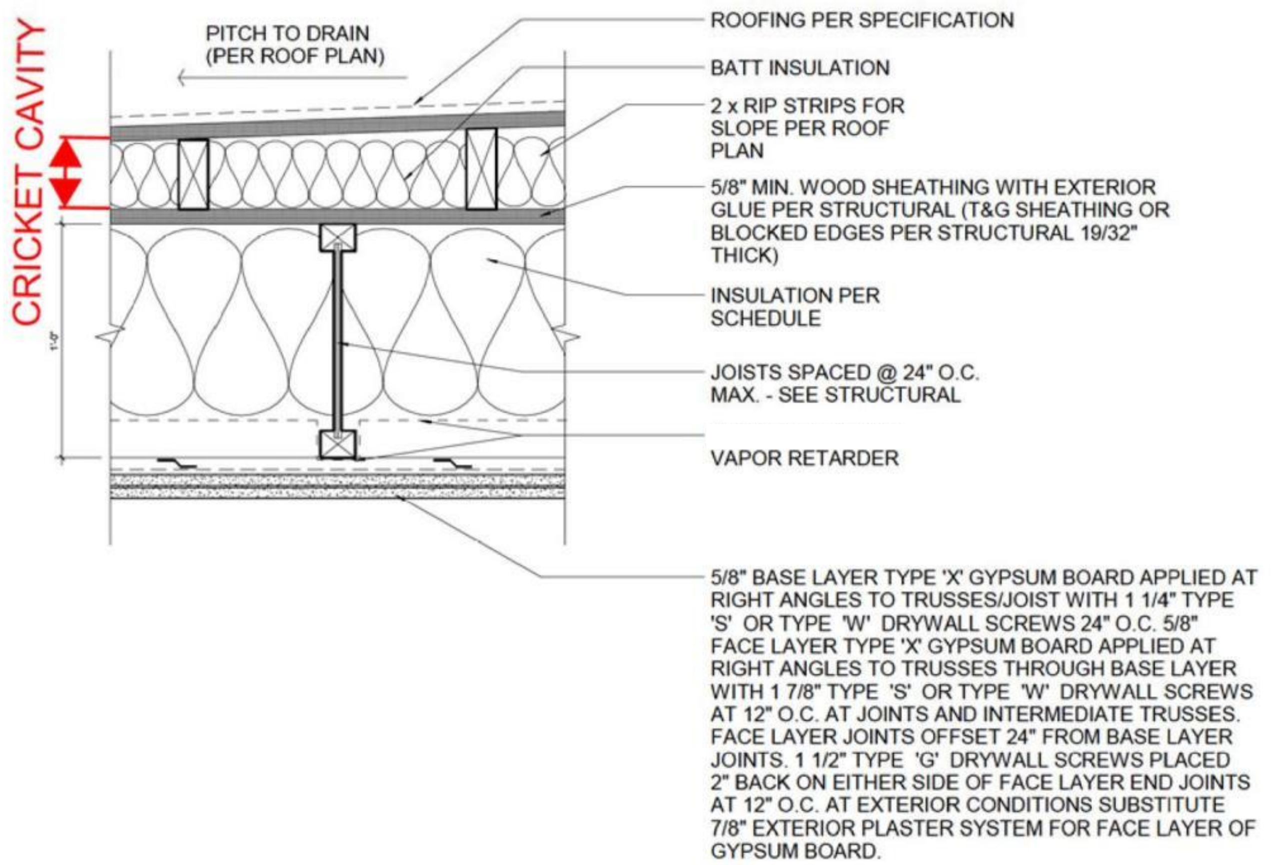
Case Study
San Francisco Apartment

Building Usage and Construction

- Building Usage
  - Residential apartment units
  - 5-9 story buildings encompassing an elevated podium common area

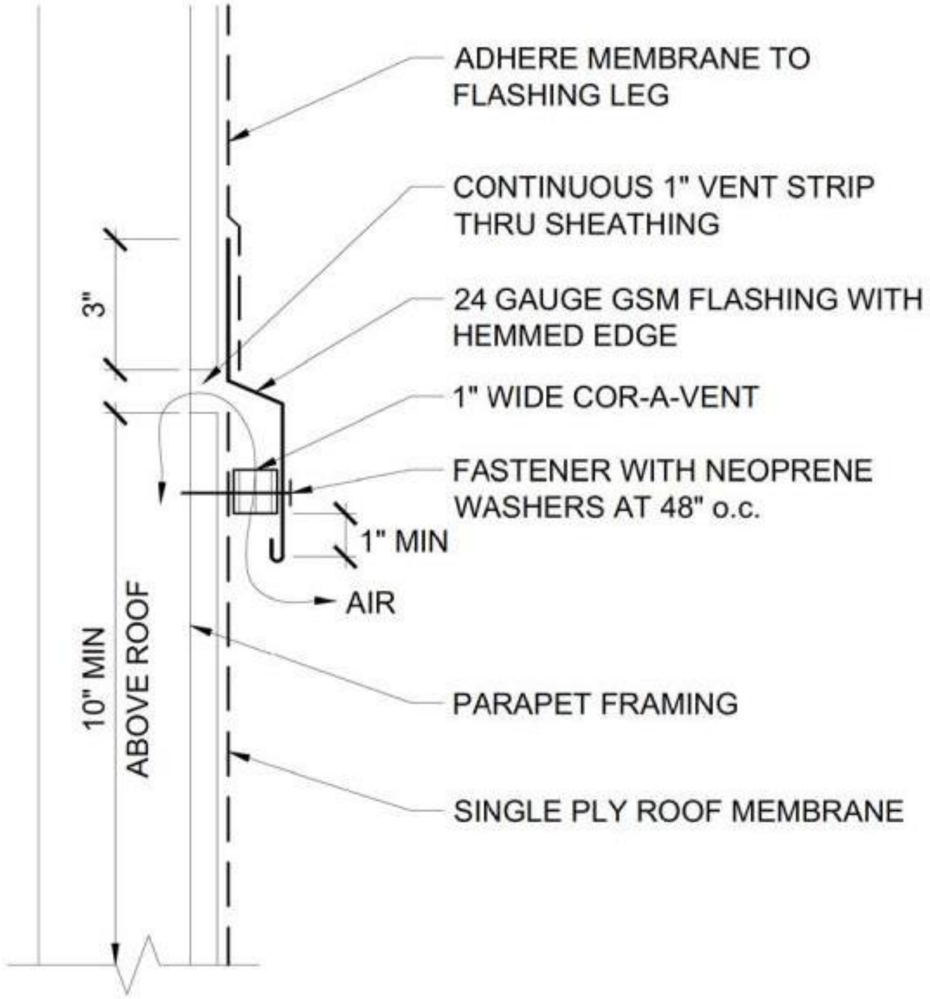
- Low-Slope Roof Assembly
  - 60 mil TPO membrane
  - 1/4” gypsum cover board, mechanically attached
  - 5/8” plywood, over 2x12 joists, over ripped 2x framing with batt insulation in cavity (Cricket Assembly)
  - Cricket assembly over 3/4” tongue and grove plywood deck (platform-framed)
  - 2x12 TJI engineered wood joists with batt insulation in cavity
  - Vapor retarder membrane
  - 2 layers of 5/8” fire rated interior gypsum
  - Mechanical curbs and photovoltaic equipment, railings, window washing & other roof-penetrating supports
  - High and low platform-framed parapet walls

Architect's Option 1 For Condensation Control

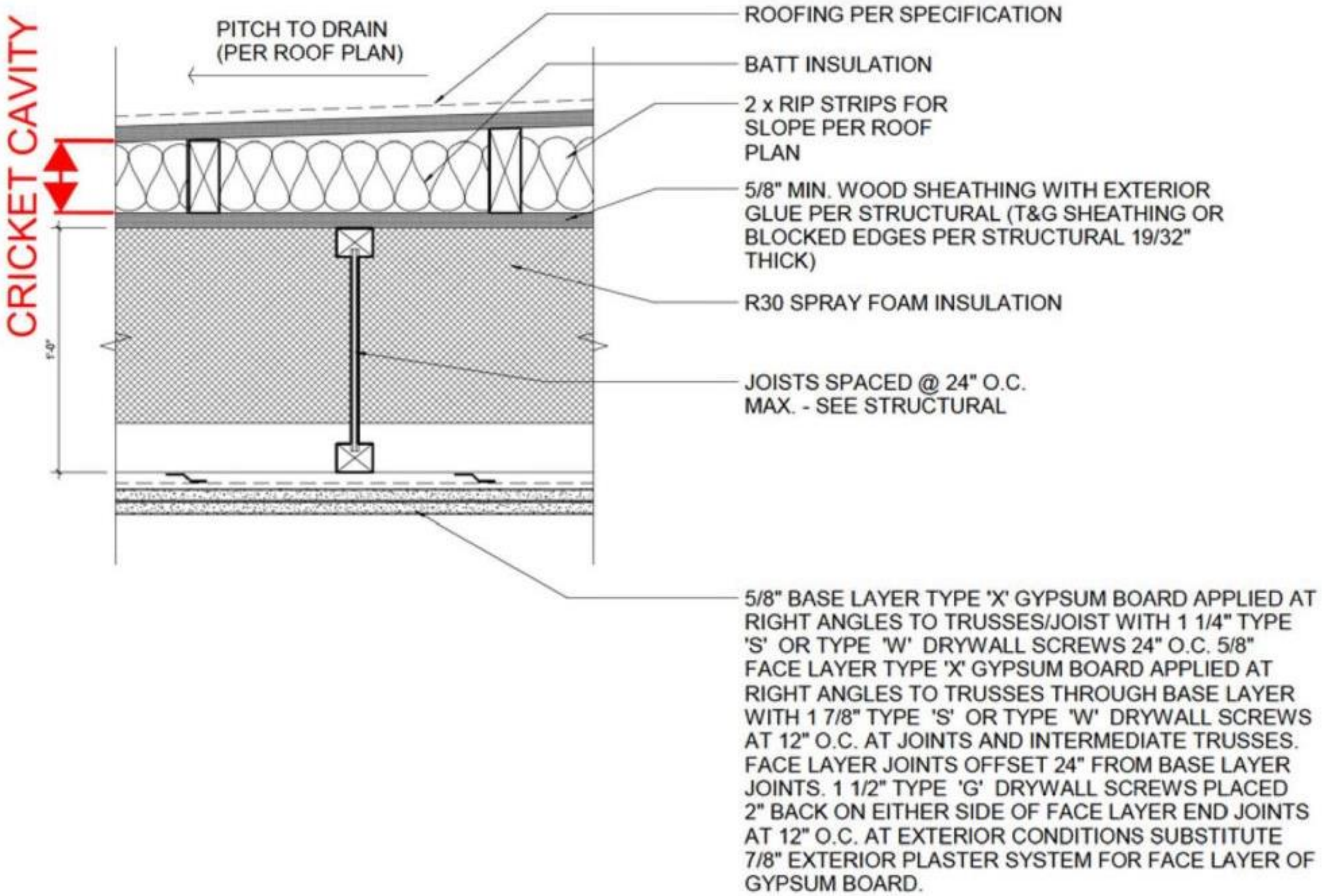


TYPICAL ROOF / CEILING | 3"=1'-0"

Architect's Option 2 For Condensation Control

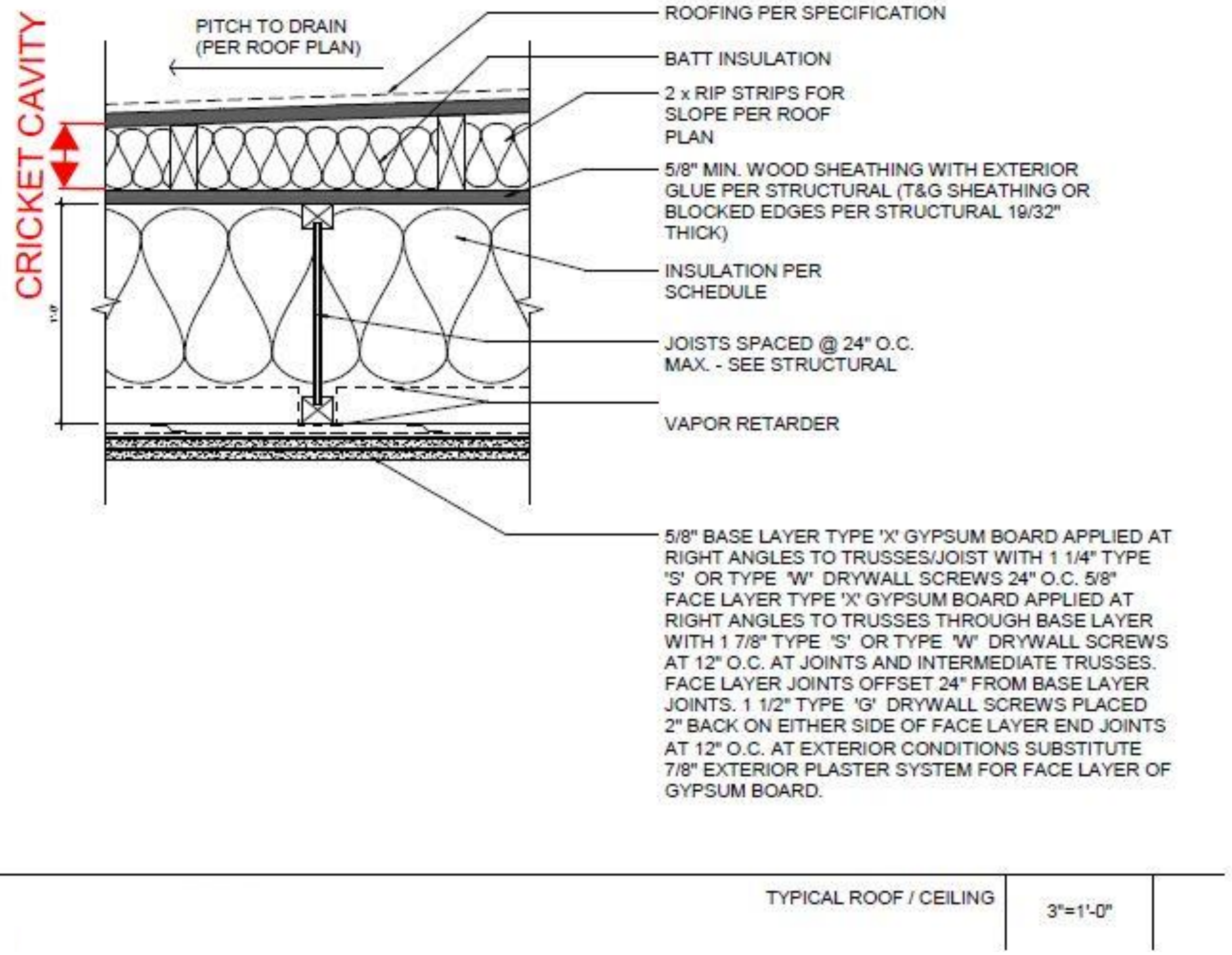


Architect's Option 3 For Condensation Control



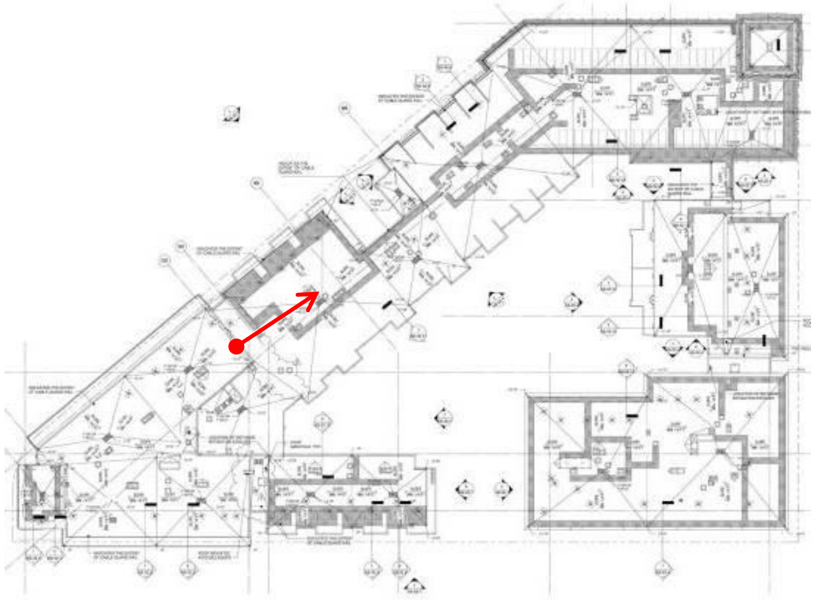
Selected Option for Condensation Control

Roof Assembly
Per Plans



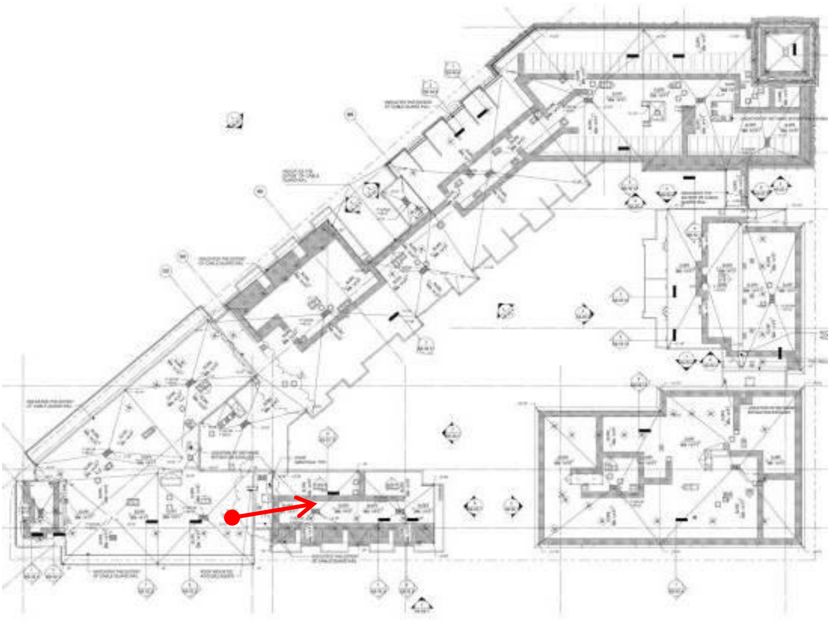
Roof Overall Photos

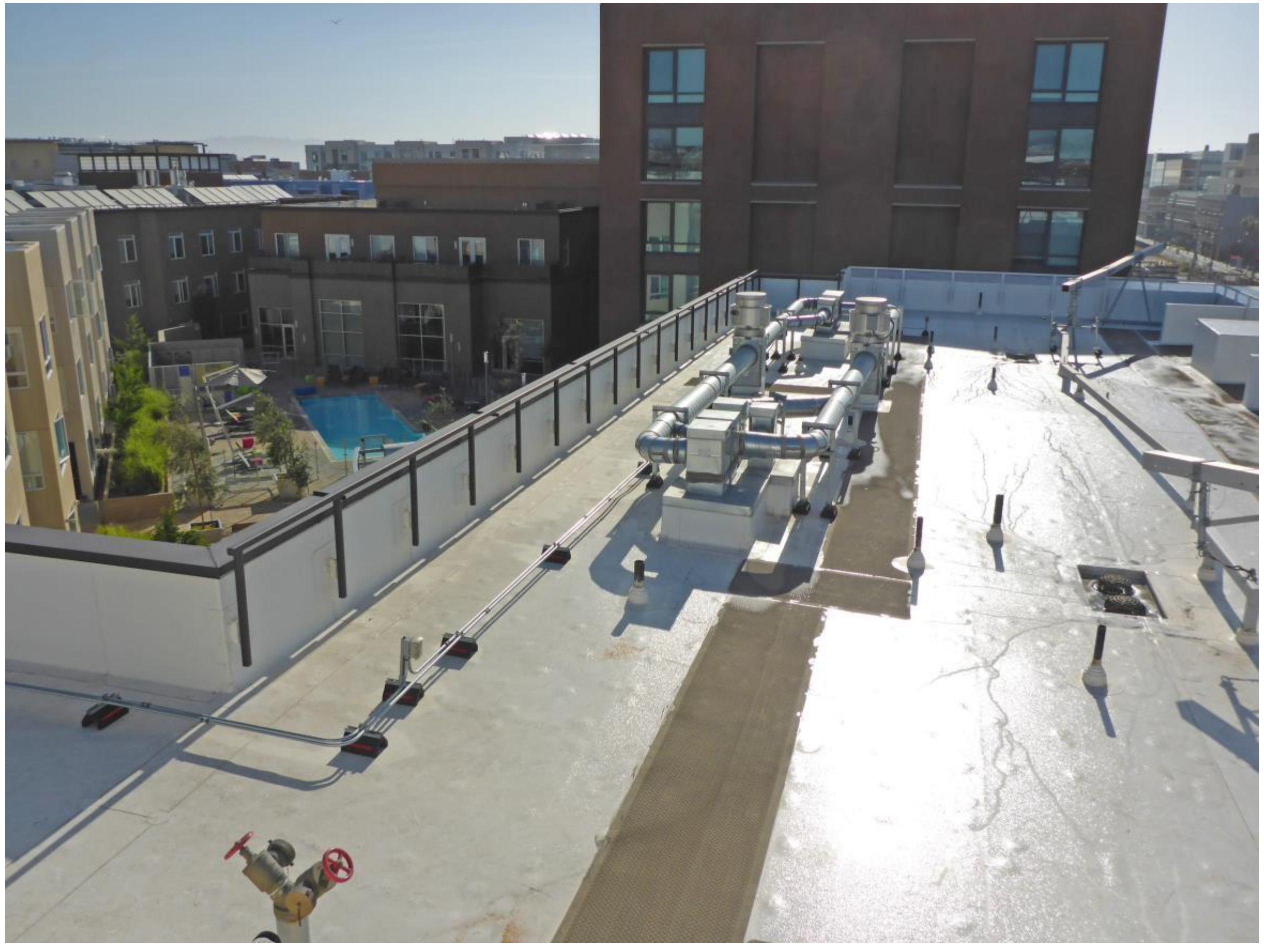
Looking northeast from
Level 6 roof upper area



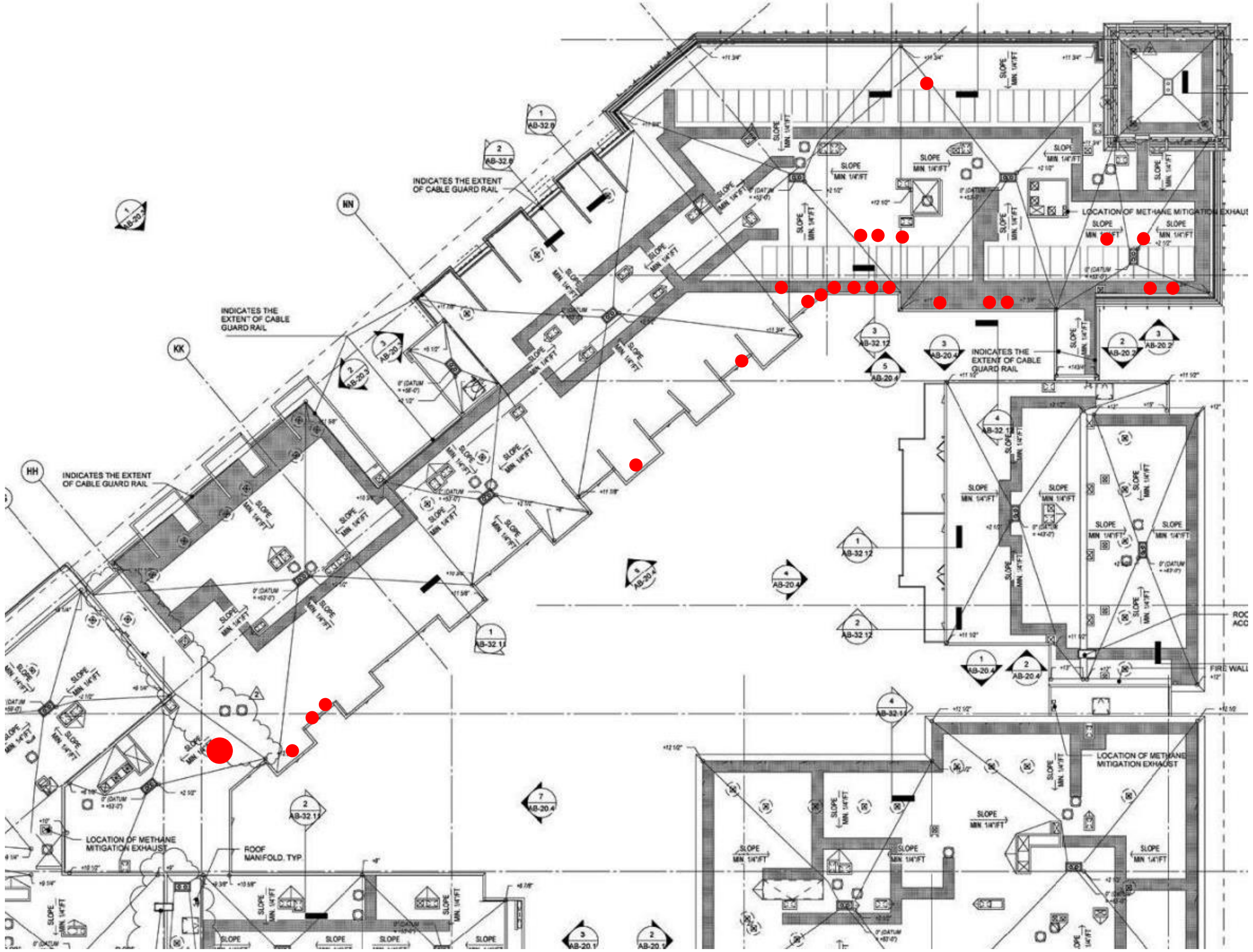
Roof Overall Photos

Looking east from Level 6 upper roof area





“Soft” Roof Substrate Identified By Walking



“Soft” Parapet Wall and Base Flashing Locations

Level 5 Roof Area

“Soft” Roofing Locations In Field of Roof

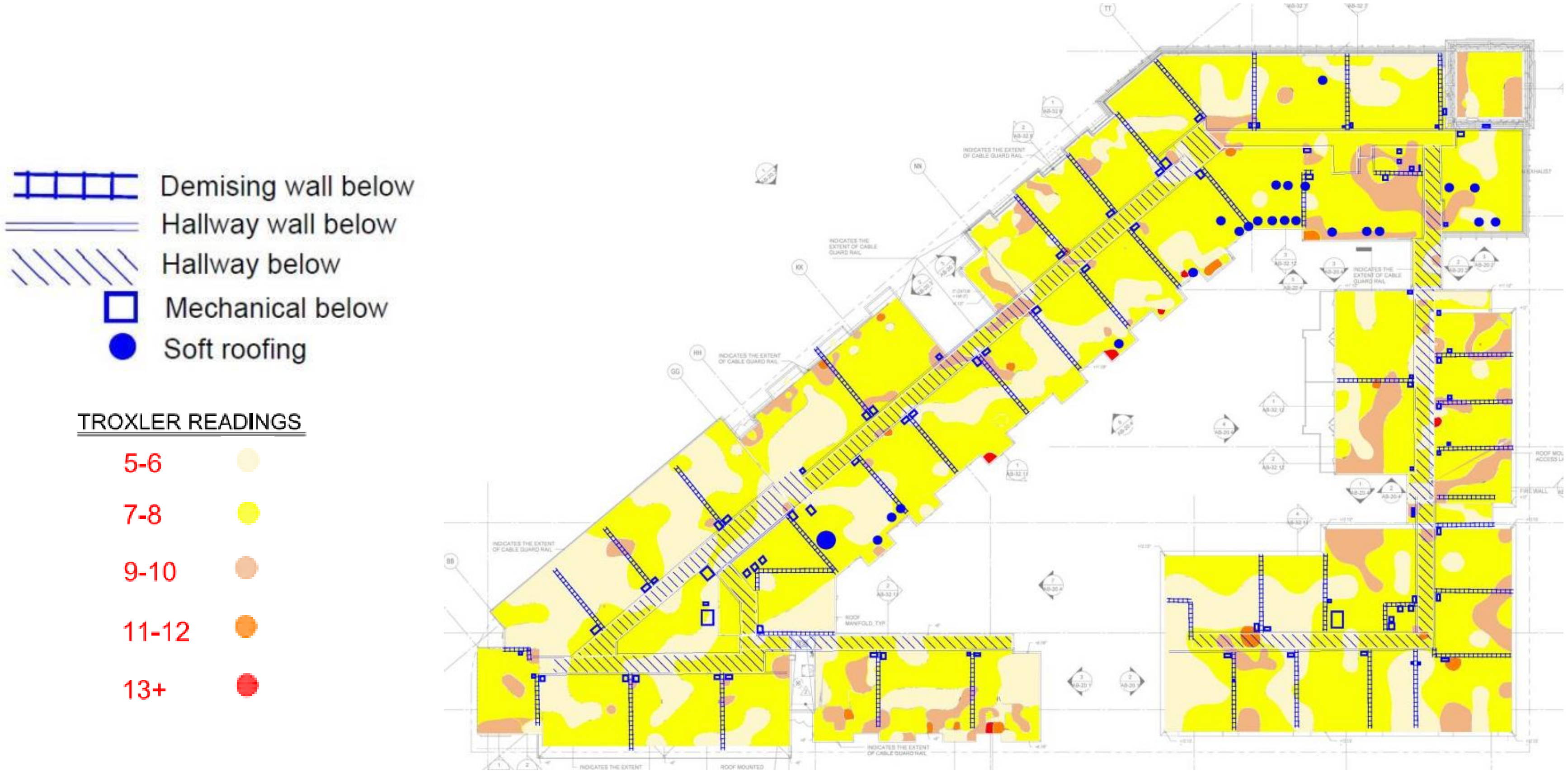
Adjacent to solar pipe stanchions and other pipe penetrations

Non-Destructive Testing and Survey

Non-Destructive Nuclear Gauge Equipment

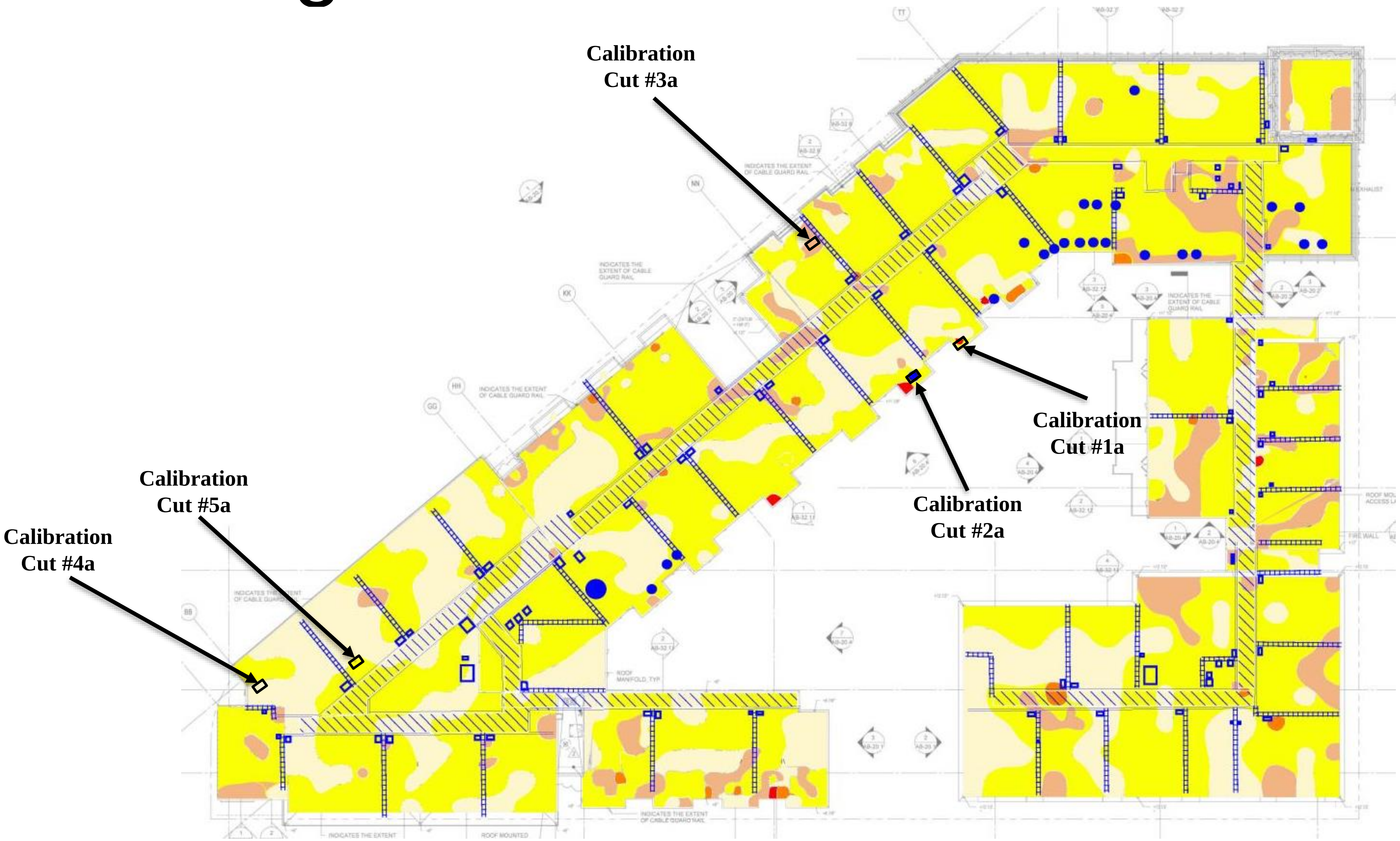
Non-Destructive Electrical Impedance Equipment

Non-Destructive Nuclear Gauge Survey Results



Calibration Roof Cuts

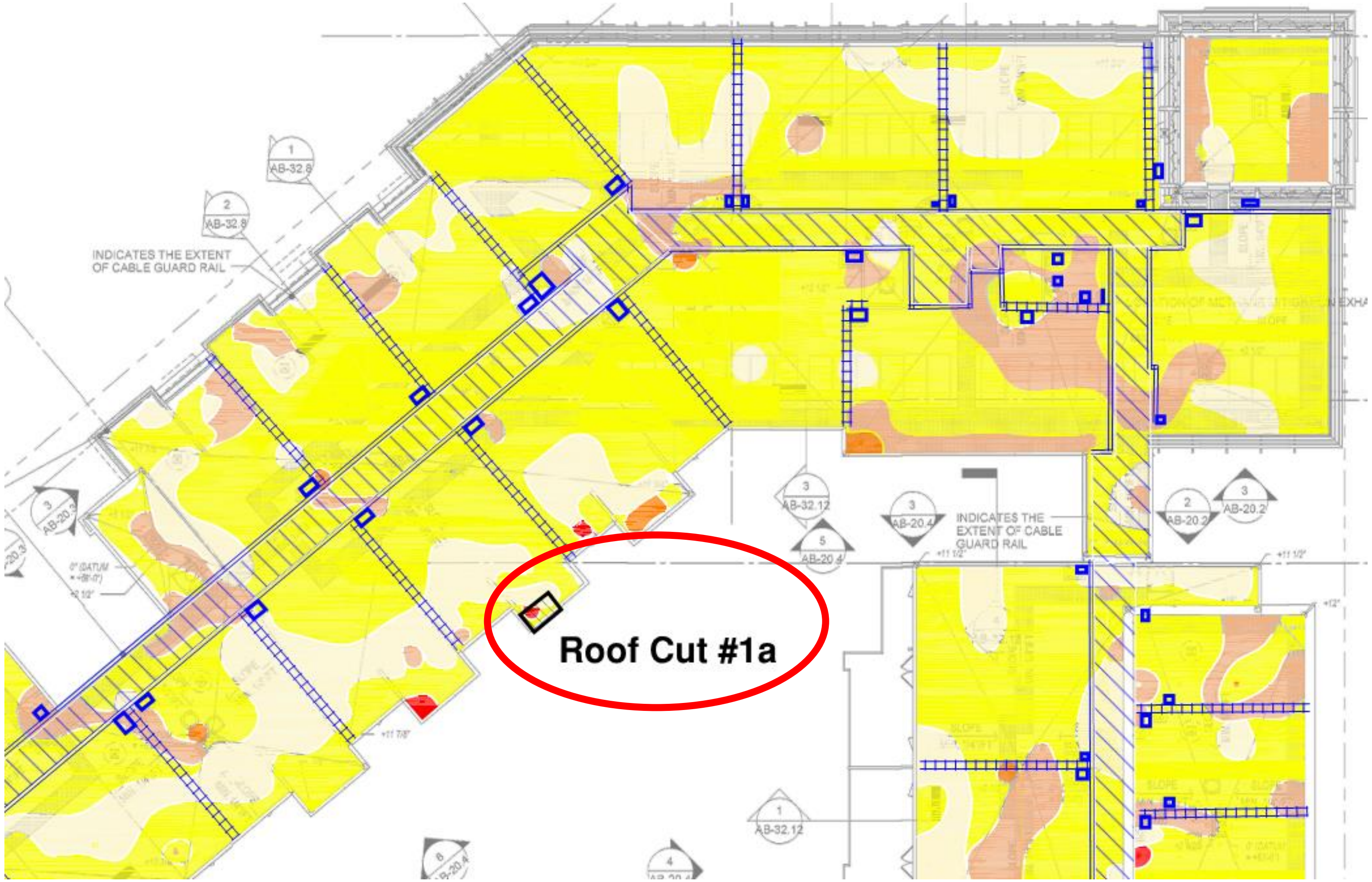
Nuclear Gauge Calibration Test Cut Locations



Calibration Test Cut #1a

Level 5 Roof Area

Test cut exhibiting damage from vapor intrusion, high nuclear gauge moisture content levels.



Damage at Cover Board and Plywood Cricket

Calibration Test Cut #1a,
Damage Level Severe
(condensation related)

<u>Nail Pull Thru Testing:</u>
5/8” Moderate Damage
Avg. 495 lb.

Damage at Plywood Cricket, Framing & Batt

Calibration Test Cut #1a,
Damage Level Severe
(condensation related)

Damage within Cricket Cavity

Calibration Test Cut #1a,
Damage Level Severe
(condensation related)

Damage on Cricket Framing

Calibration Test Cut #1a, Damage Level Severe (condensation related)

Damage Limited to this area

Topside View of Structural Plywood Sheathing

Calibration Test Cut #1a

<u>Nail Pull Thru Testing:</u>
3/4” Moderate Damage
Avg. 285 lb.

Stained Insulation Batt in Roof Cavity

Calibration Test Cut #1a

Calibration Test Cuts – Summary

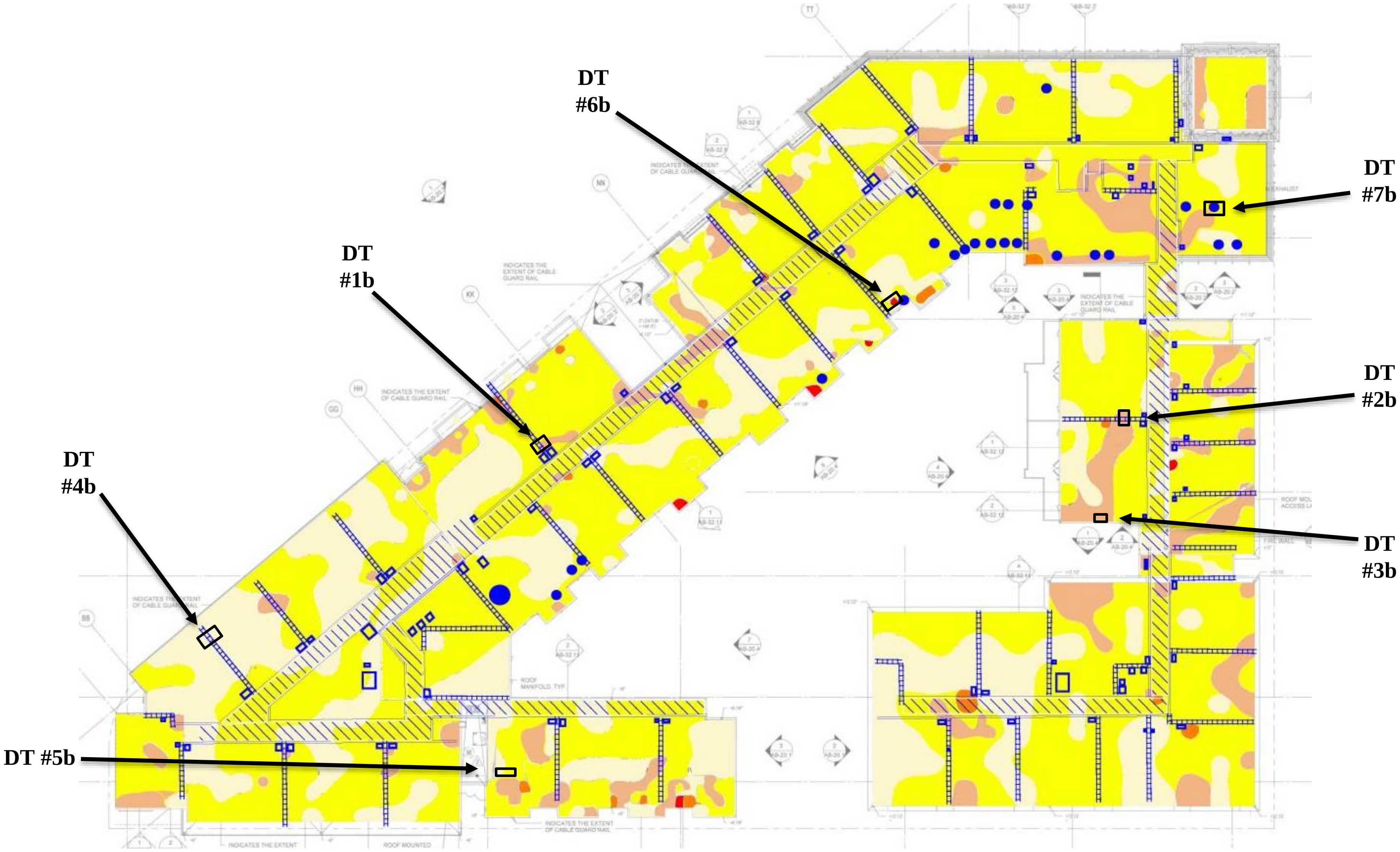
	Roof Cut #1a	Roof Cut #2a	Roof Cut #3a	Roof Cut #4a	Roof Cut #5a
Building Level	5	5	5	6	6
Troxler Reading	19	6	11	5	9
Damage Level	900	700, 701	700, 801	701	700, 701
Notes		ST			

Damage Level Key:
700 - Slight damage due to Condensation
701 - Slight damage due to exposure to rain during construction
800 - Moderate damage due to Condensation
801 - Moderate damage due to exposure to rain during construction
900 - Severe damage due to Condensation
901 - Severe damage due to exposure to rain during construction

Notes Key:
ST - Staple not installed into framing at vapor retarder layer

Other Destructive Testing Cuts

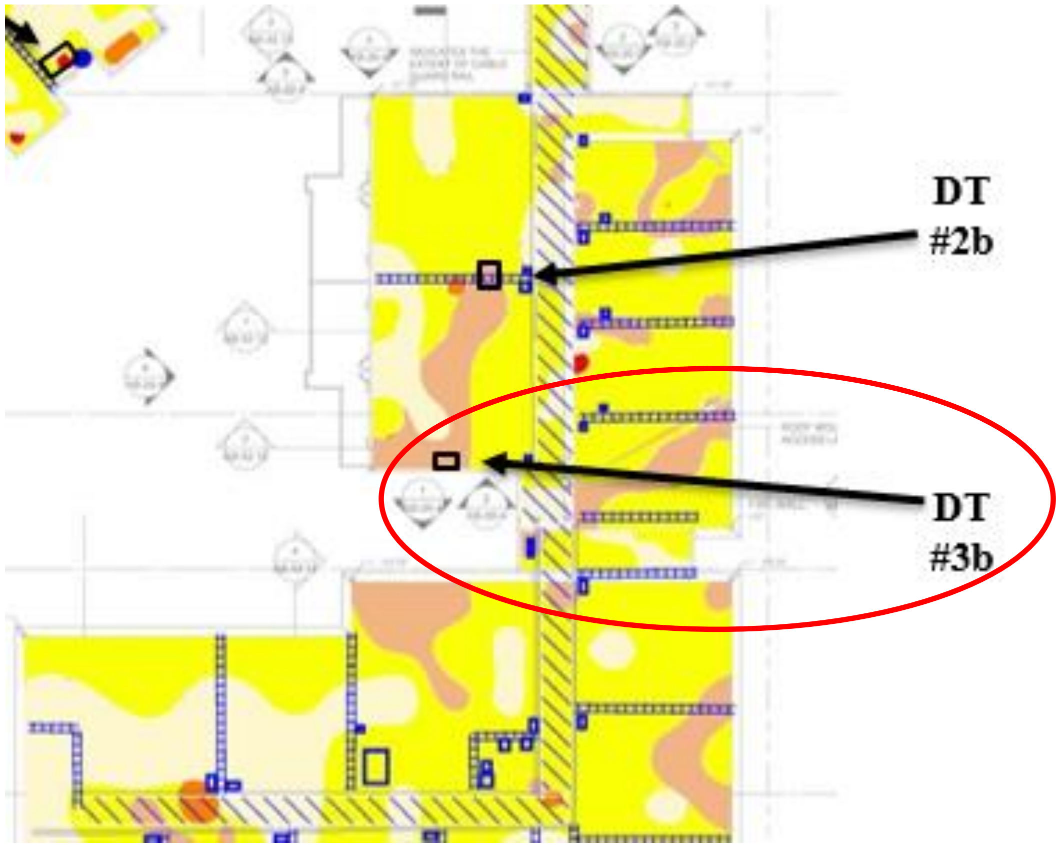
Destructive Testing Cut Locations



Destructive Test Cut #3b

- Test Cut Location: Level 5 Roof Area, Roof to parapet wall

- Test cut exhibiting severe damage from vapor intrusion, and had a moderate nuclear gauge reading.



Damaged Plywood Cricket and Cover Board

Test Cut #3b, Damage Level 900 (condensation related)

<u>Nail Pull Thru Testing:</u>
5/8" Moderate Damage
Avg. 298 lb.

Saturated moisture levels

Damage on Backside of Plywood Cricket

Destructive Test
Cut #3b

Water and Staining within Cricket Cavity

Destructive

Test Cut #3b

<u>Nail Pull Thru Testing:</u>
5/8" Moderate Damage
Avg. 586 lb.

Corroding Fastener in Cricket Sheathing

Destructive Test Cut #3b,

Destructive Test Cut #7b

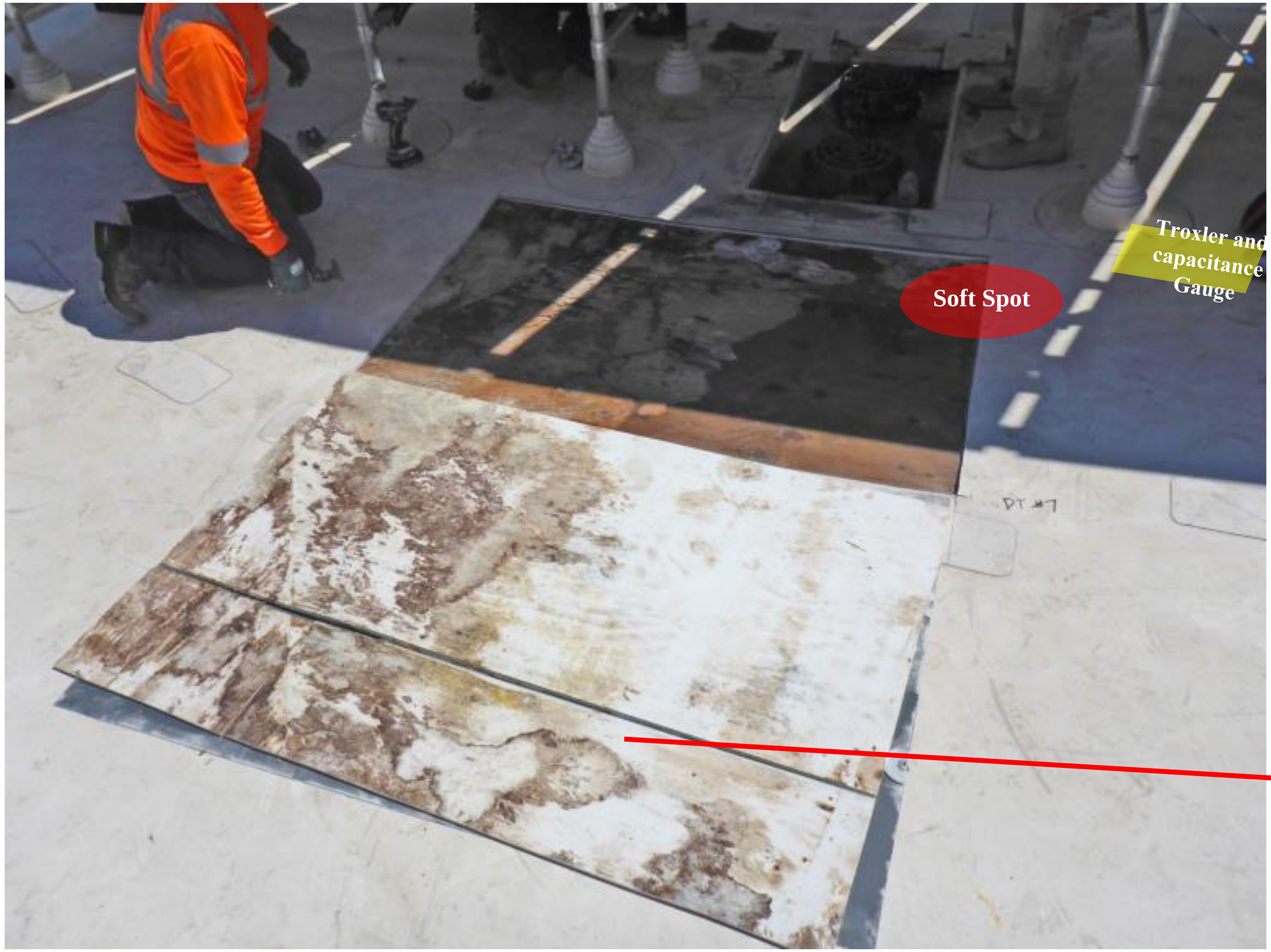
- Test Cut Location: Level 5 Roof Area, Adjacent to roof drains

- Test cut exhibiting severe condensation damage, noted soft spot, had a low Troxler reading, and had high Tramex moisture content levels.

Moisture Scan Results

Destructive Test Cut #7b (Soft Spot)

Destructive Testing Cut # 7b, Severe Damage



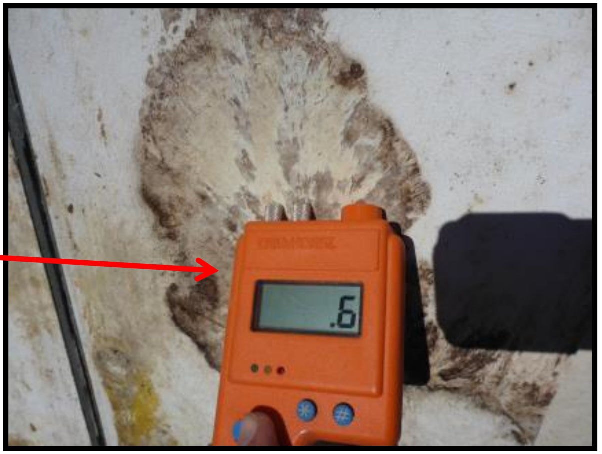
<u>Nail Pull Thru Testing:</u>

5/8” Severe Damage

Avg. 98 lb.

5/8” Slight Damage

Avg. 354 lb.



Destructive Testing Cut # 7b, Severe Damage

Destructive Test Cut #7b,
Damage Level 900
(condensation related)

Wood Rot and Elevated Moisture Content

Destructive Test Cut #7b

Plywood Cricket Wood Rot and Organic Growth

Destructive Test Cut #7b

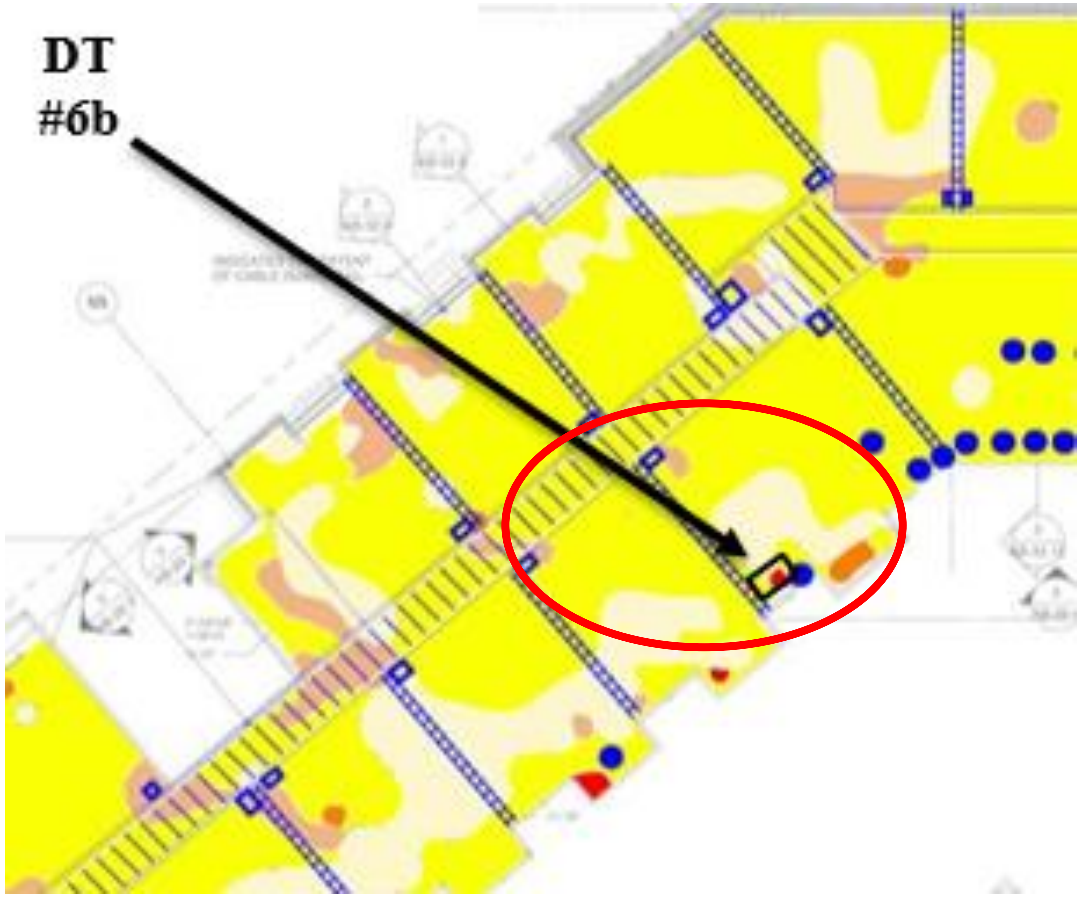
Corroding Drain Bowl

Destructive Test Cut #7b

Destructive Test Cut #6b

- <u>Test Cut Location:</u> Level 5 Roof Area, Roof to parapet wall

- Test cut exhibiting severe condensation damage, noted soft spot, and had a high nuclear guage reading.



Moisture Between Membrane and Cover Board

Destructive Test Cut #6b

Moisture Between Membrane and Cover Board

Destructive Test Cut #6b, Damage level 900 (condensation related)

Plywood Cricket Wood Rot and Organic Growth

Destructive Test Cut #6b, Damage level 900 (condensation related)

Plywood Cricket Wood Rot and Organic Growth

Destructive Test Cut #6b, Damage level 900 (condensation related)

Nail Pull Thru Testing:

5/8” Very Severe Damage Avg. **28 lb.**

5/8” Moderate Damage Avg. **269 lb.**

5/8” Slight Damage Avg. **354 lb.**

Severe Damage at Metal Hand Railing Base

Destructive Test Cut #6b, Damage level 900 (condensation related)

Destructive Test Cuts – Damage Summary

	Roof Cut #1b	Roof Cut #2b	Roof Cut #3b	Roof Cut #4b	Roof Cut #5b	Roof Cut #6b	Roof Cut #7b
Building Level	5	5	5	6	5	5	5
Troxler Reading	9	10	10	6	7	19	9
Damage Level	800	800, 801	900, 801	801	800, 701	900, 801	900, 801
Notes	SS	PP, EC, OL	SS, EC	SS, ST	PP, SS, TM	SS	SS, ST

Damage Level Key:
700 - Slight damage due to Condensation
701 - Slight damage due to exposure to rain during construction
800 - Moderate damage due to Condensation
801 - Moderate damage due to exposure to rain during construction
900 - Severe damage due to Condensation
901 - Severe damage due to exposure to rain during construction

Notes Key:
SS - Screw fastener not installed into framing / shiner at vapor retarder layer
PP - Pipe penetration not sealed at vapor retarder layer
EC - Electrical conduit not sealed at vapor retarder layer
OL - Open lap seam within vapor retarder layer
ST - Staple not installed into framing at vapor retarder layer
TM - Tear in vapor retarder layer

Plywood Nail Pull Through Testing

Adapted from ASTM D1037

Photos of Pull Testing

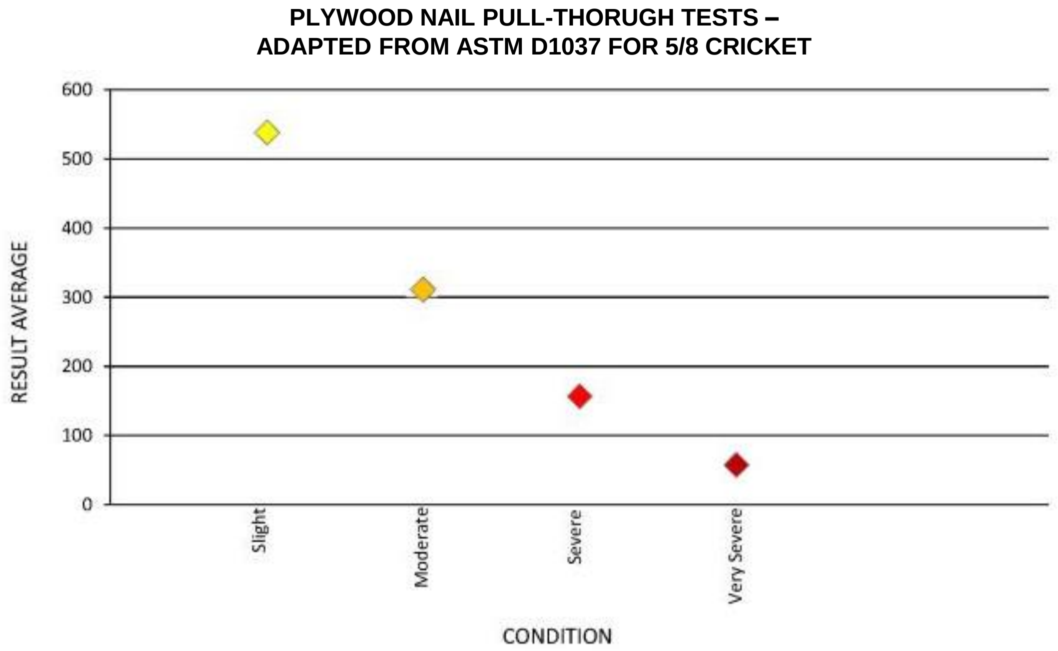
Plywood sample retained in the field with nail pull thru testing locations

Photos of Pull Testing

COM-TEN Digital Pull Tester in place during testing

Nail Pull Through - 5/8” Cricket Sheathing

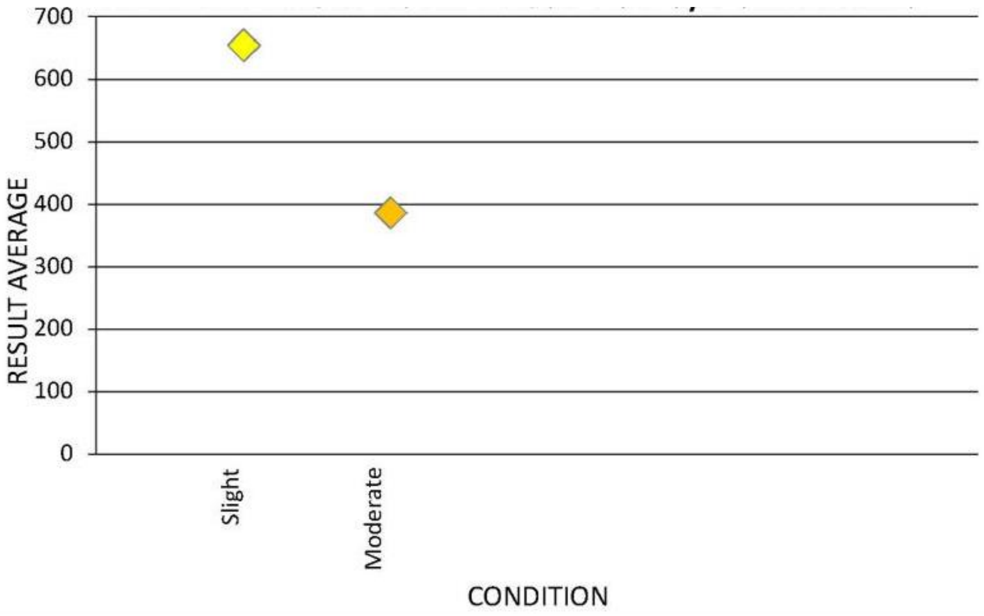
Test #	Sample Location	Condition	Result (lb.)	Average for Condition
5/8 Cricket				
P5	Calibration roof cut #2	Slight	672.5	538.9
P6	Calibration roof cut #2	Slight	579.2	
P8	Calibration roof cut #3	Slight	520.2	
P9	Calibration roof cut #3	Slight	591.1	
P11	Calibration roof cut #5	Slight	741.6	
P12	Calibration roof cut #5	Slight	533.5	
P14	Calibration roof cut #4	Slight	435	
P15	Calibration roof cut #4	Slight	547.1	
P23	Destructive Test Cut #7	Slight	342.5	
P24	Destructive Test Cut #7	Slight	411.3	
P34	DT Cut #1	Slight	480.3	
P35	DT Cut #1	Slight	518.6	
P36	DT Cut #1	Slight	561.7	
P37	DT Cut #3	Slight	586	
P41	DT Cut #3	Slight	562.7	
P1	Calibration roof cut #1	Moderate	528.4	311.6
P2	Calibration roof cut #1	Moderate	461.1	
P18	Destructive Test Cut #6	Moderate	354.1	
P20	Destructive Test Cut #7	Moderate	269.8	
P27	Prior Testing	Moderate	246.2	
P29	Prior Testing	Moderate	158.8	
P33	Prior Testing	Moderate	202.4	
P38	DT Cut #3	Moderate	258.5	
P39	DT Cut #3	Moderate	375.5	
P40	DT Cut #3	Moderate	261.3	
P17	Destructive Test Cut #6	Severe	79.5	157.0
P21	Destructive Test Cut #7	Severe	539.5	
P22	Destructive Test Cut #7	Severe	96	
P28	Prior Testing	Severe	181.4	
P30	Prior Testing	Severe	85.7	
P31	Prior Testing	Severe	38.3	
P32	Prior Testing	Severe	78.8	
P19	Destructive Test Cut #6	Very Severe	27.9	58.2
P25	Destructive Test Cut #7	Very Severe	16.4	
P26	Prior Testing	Very Severe	130.3	



Nail Pull Through - 3/4” Roof Sheathing

Test #	Sample Location	Condition	Result (lb.)	Average for Condition
3/4 Sheathing				
P10	Calibration roof cut #3	Slight	636	655.1
P13	Calibration roof cut #5	Slight	674.2	
P7	Calibration roof cut #2	Moderate	417.7	387.0
P3	Calibration roof cut #1	Moderate	284.6	
P16	Calibration roof cut #4	Moderate	458.7	

PLYWOOD NAIL PULL-THORUGH TESTS –
ADAPTED FROM ASTM D1037 FOR 3/4 SHEATHING



Vapor Retarder Membrane Installation

Manufacturer's Instructions for Tears and Holes

MemBrain Sheet Tears and Holes

- Cover all tears and holes with recommended sheathing tape.
- Treat large holes (greater than 1 inch) like large penetrations using a square patch.

Large Circular Penetrations – Figures 10 and 11

- Trace the penetration circumference on a separate piece of MemBrain sheeting.
- Cut a square piece of film with a minimum 6-inch clearance from the penetration outline.
- Intersect the circle with four diameter lines. (See Figure 10.)
- Cut according to these lines towards the circle's perimeter.
- Place the square patch over the penetration. (See Figure 11.)
- Seal the cut edges to the penetration with recommended sheathing tape.
- Seal the square patch to the continuous sheet surface without film tension using recommended sheathing tape and lightly press to ensure complete contact.

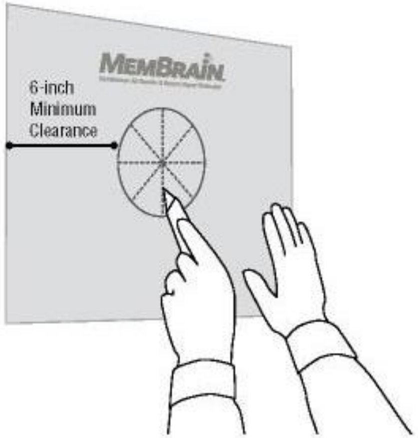


Figure 10: Patch preparation.

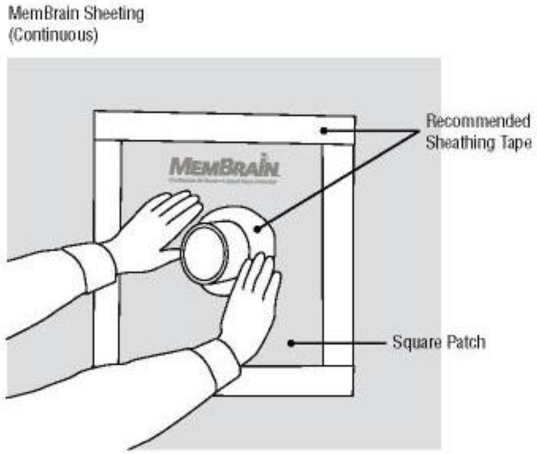


Figure 11: Patch attachment.

Vapor Retarder Installation Instructions at Walls

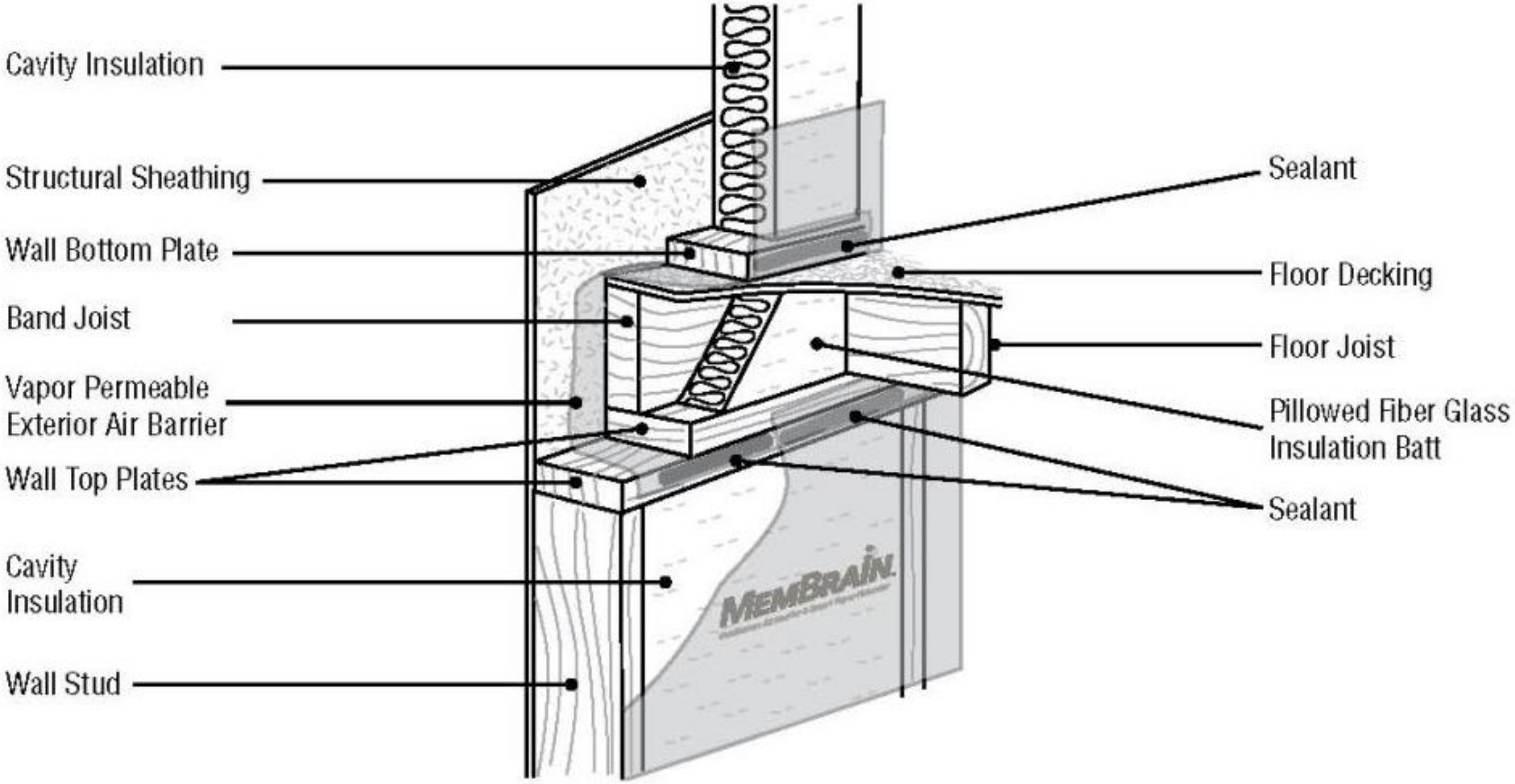


Figure 17: *Detail B – MemBrain Air Barrier System interior floor intersection details.*

Defects Associated With Vapor Retarder

- 1.01 - Unsealed laps in vapor retarder
- 1.02 - Vapor retarder unsealed at penetrations
- 1.03 - Torn vapor retarder
- 1.04 - Drywall screws not installed into framing
- 1.05 - Improperly terminated at parapet wall

1.01 Unsealed Lap in Vapor Retarder

Destructive Test Cut #2b

Vapor Retarder Unsealed at Penetrations

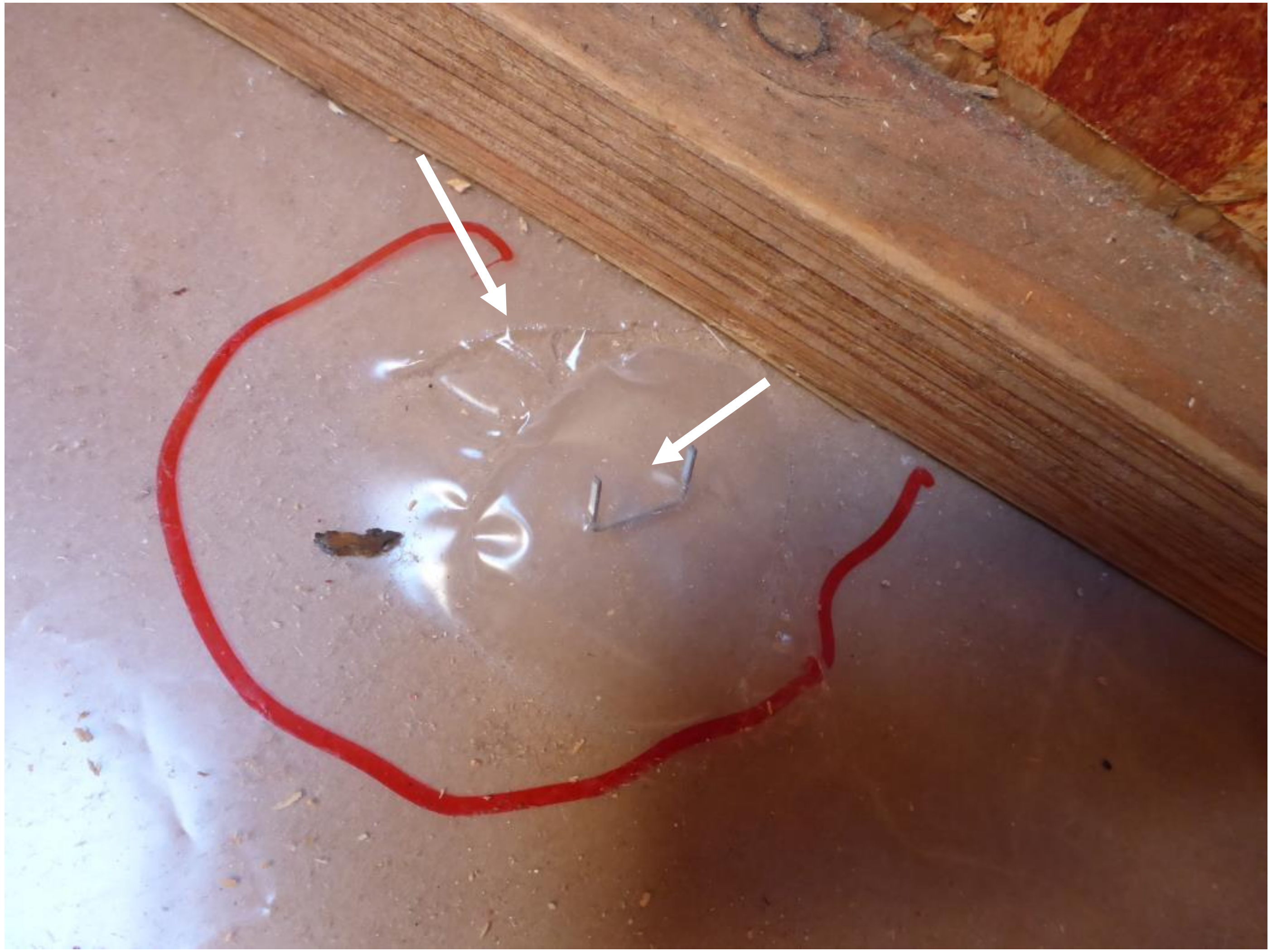
Destructive Test Cut #2b

Vapor Retarder Unsealed at Pipe Penetrations

Destructive Test Cut #5b

Torn Vapor Retarder

Destructive Test Cut #4b

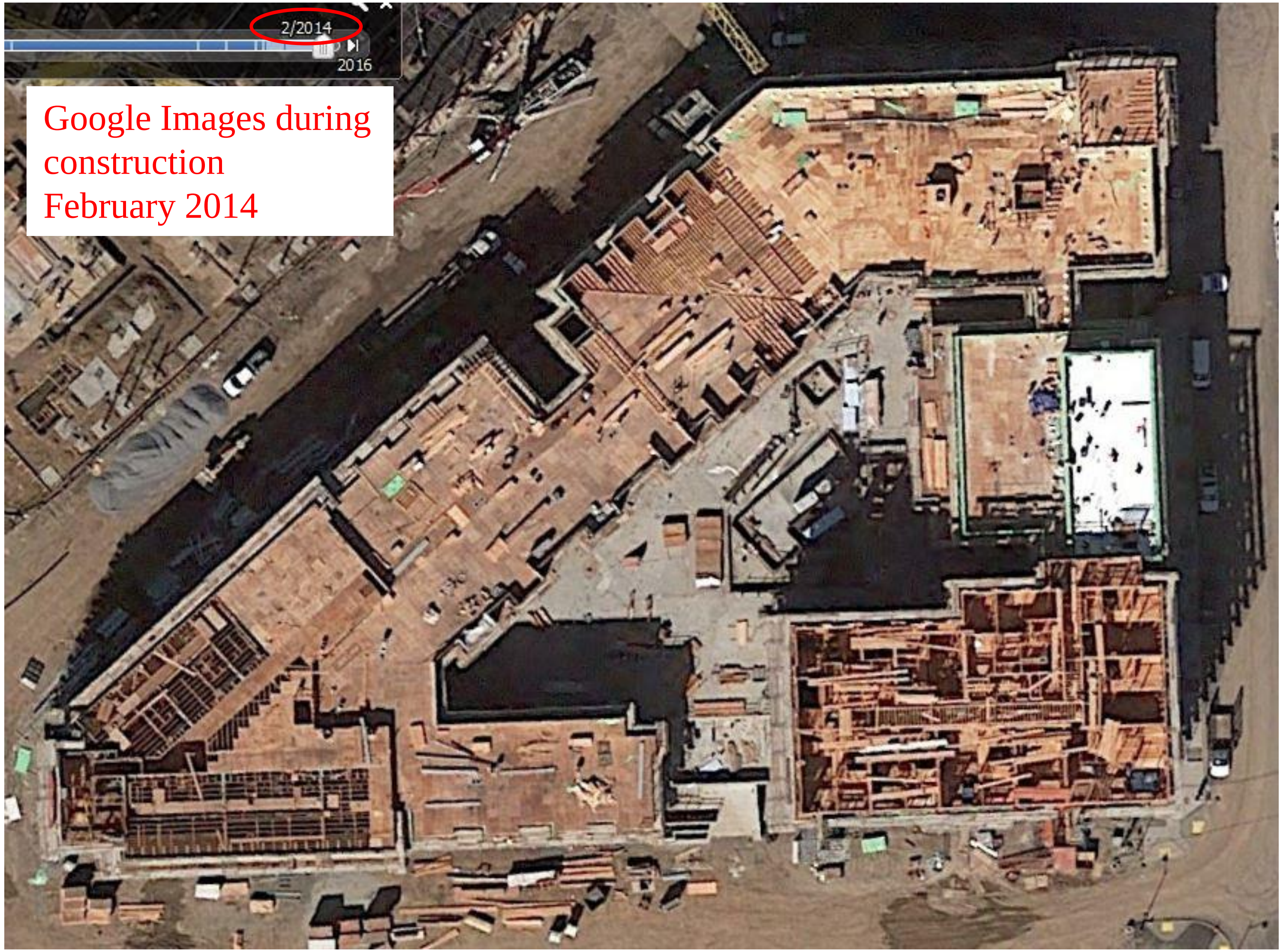


Drywall Screws Not Installed in to Framing

Destructive Test Cut #5b

Damage from Weather Exposure

Weather Exposure



Weather Exposure – Historic Weather Data

February 2014

Monthly Total Precipitation for SAN FRANCISCO INTL AP, CA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2014	0.01	3.76	1.93	1.61	T	T	T	T	0.42	0.31	1.99	10.66	20.69
Mean	0.01	3.76	1.93	1.61	T	T	T	T	0.42	0.31	1.99	10.66	20.69
Max	0.01 2014	3.76 2014	1.93 2014	1.61 2014	T 2014	T 2014	T 2014	T 2014	0.42 2014	0.31 2014	1.99 2014	10.66 2014	20.69 2014
Min	0.01 2014	3.76 2014	1.93 2014	1.61 2014	T 2014	T 2014	T 2014	T 2014	0.42 2014	0.31 2014	1.99 2014	10.66 2014	20.69 2014

Source: National Weather Service Forecast Office

Weathered Sheathing and Rusted Fasteners

Destructive Test Cut #1b

Damage Underneath the Plywood Deck Edge

Water Damage Due to Rain

Damage Underneath Plywood Cricket

Destructive Test Cut #1b (Bottom of Structural Roof Sheathing)

Damage was at the top, water soaked through the T&G joints

Roofing Repair Action

- Demolition and replacement of 100% of cricket plywood and framing
- Selective replacement of structural sheathing where damaged
- Replacement of 100% of the roofing and flashings
- Replacement of 100% the sheet metal roofing coping caps

Designing Roofs to Mitigate Condensation

- Self Drying Roofs
  - Cool Roofs change the dynamic
- Vapor Retarders
  - Continuity, location, product
- Ventilation
  - Passive vs. Active (mechanical)

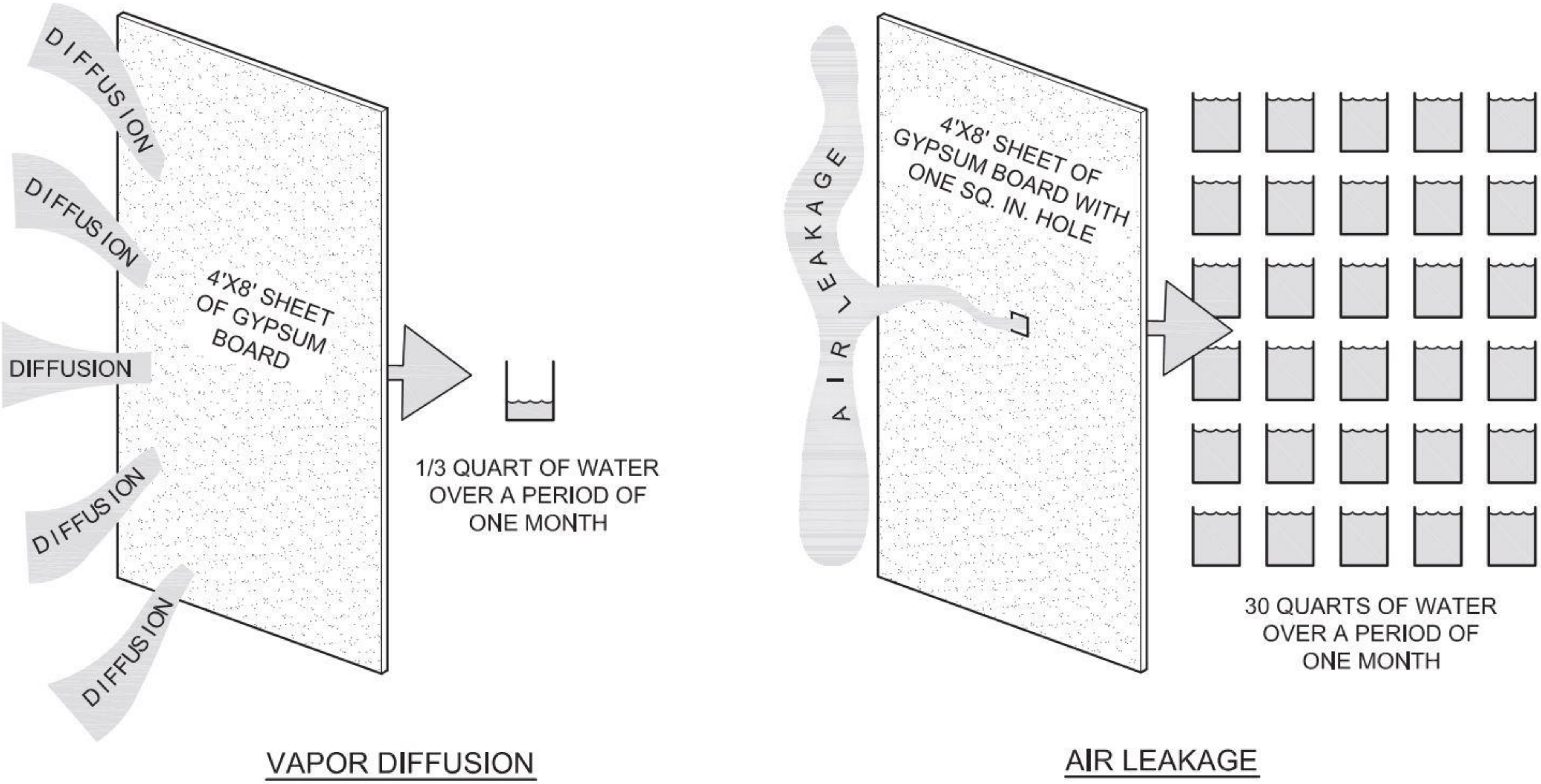
Vapor Retarder Design Concepts

What is a Vapor Retarder?

- If it’s less than or equal to 10 perms, it’s a vapor retarder.
  - Plywood
  - Asphalt Saturated Sheathing Paper
  - Polyethylene
  - PVC Roof Membrane

- Permeance vs. Permeability
  - Permeance is the vapor transmission rate through a material of a given thickness; stated in perms.
  - Permeability is a material property and is the arithmetic product of permeance and thickness; stated in perm-inches.

Vapor Diffusion vs. Air Leakage



Vapor Retarder Classifications

2016 CA Residential Code

[RB] VAPOR RETARDER CLASS. A measure of the ability of a material or assembly to limit the amount of moisture that passes through that material or assembly. Vapor retarder class shall be defined using the desiccant method with Procedure A of ASTM E96 as follows:

2016 CA Building Code

VAPOR RETARDER CLASS. A measure of a material or assembly's ability to limit the amount of moisture that passes through that material or assembly. Vapor retarder class shall be defined using the desiccant method of ASTM E96 as follows:

Classification	Definition	Terms
I	≤ 0.1 per	Vapor Impermeable
II	> 0.1 perm, ≤ 1.0 perm	Vapor Semi-Impermeable
III	> 1.0 perm, ≤ 10 perm	Vapor Semi-Permeable
None	> 10 perm	Vapor Permeable

Vapor Retarder Test Methods

ASTM E96

X1. STANDARD TEST CONDITIONS

X1.1 Standard test conditions that have been useful are:

X1.1.1 *Procedure A*—Desiccant Method at 73.4°F [23°C].

X1.1.2 *Procedure B*—Water Method at 73.4°F [23°C].

X1.1.3 *Procedure BW*—Inverted Water Method at 73.4°F [23°C].

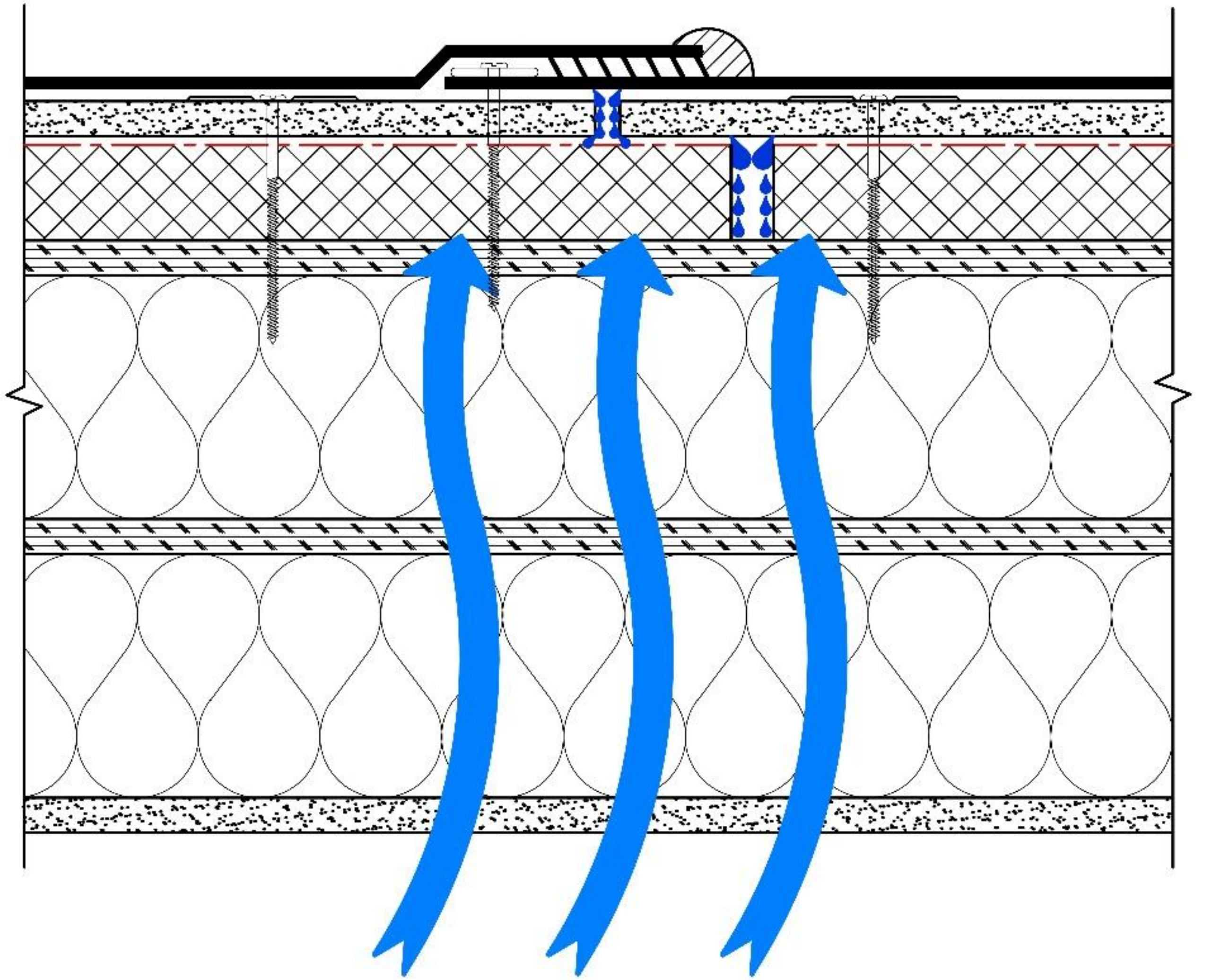
X1.1.4 *Procedure C*—Desiccant Method at 90°F [32.2°C].

X1.1.5 *Procedure D*—Water Method at 90°F [32.2°C].

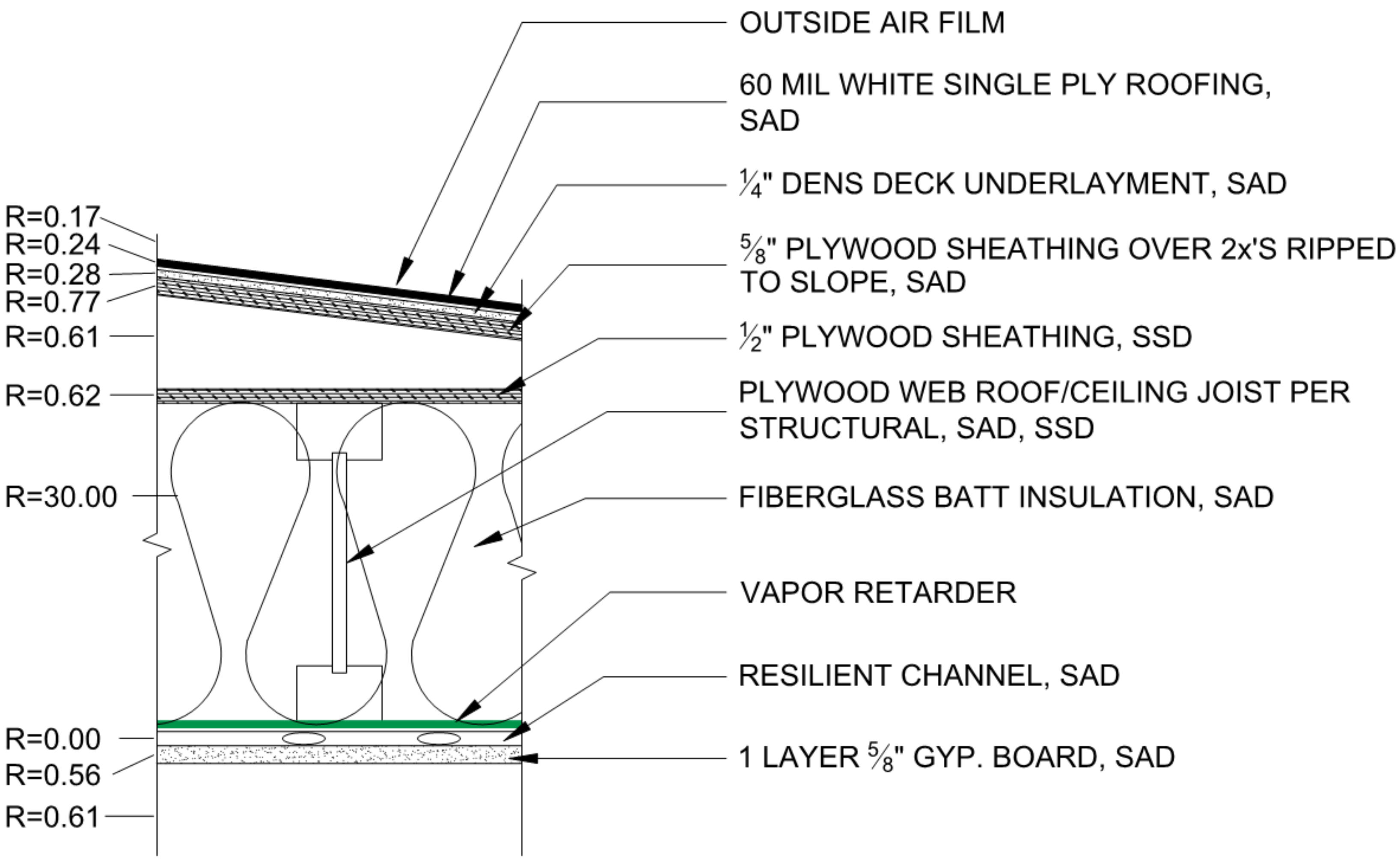
X1.1.6 *Procedure E*—Desiccant Method at 100°F [37.8°C].

X1.2 Unless otherwise prescribed by regulation, specification, ASTM standard, or other governing document, select test conditions similar to those to which the material will be exposed to actual use.

Condensation Occurs At Dew Point



Wood Frame Roof – 1-Hr Assembly



Typical Roof / Ceiling - 1Hr Assembly

Winter conditions, heat flow upwards

Assume outside temperature 34°
Assume inside temperature 72°, 60% R.H.

Temperature at P1, P2, P3, P4: $T_{P1} = T_i - \left[\left(\frac{\Sigma R_1}{\Sigma R}\right)(T_i - T_o)\right]$

$\Sigma R = 0.61 + 0.56 + 30.0 + 0.62 + 0.61 + 0.77 + 0.28 + 0.24 + 0.17 = 33.86$

$\Sigma R_1 = 0.61 + 0.56 = 1.17$

$\Sigma R_2 = 0.61 + 0.56 + 30.0 = 31.17$

$\Sigma R_3 = 0.61 + 0.56 + 30.0 + 0.62 = 31.79$

$\Sigma R_4 = 0.61 + 0.56 + 30.0 + 0.62 + 0.61 = 32.4$

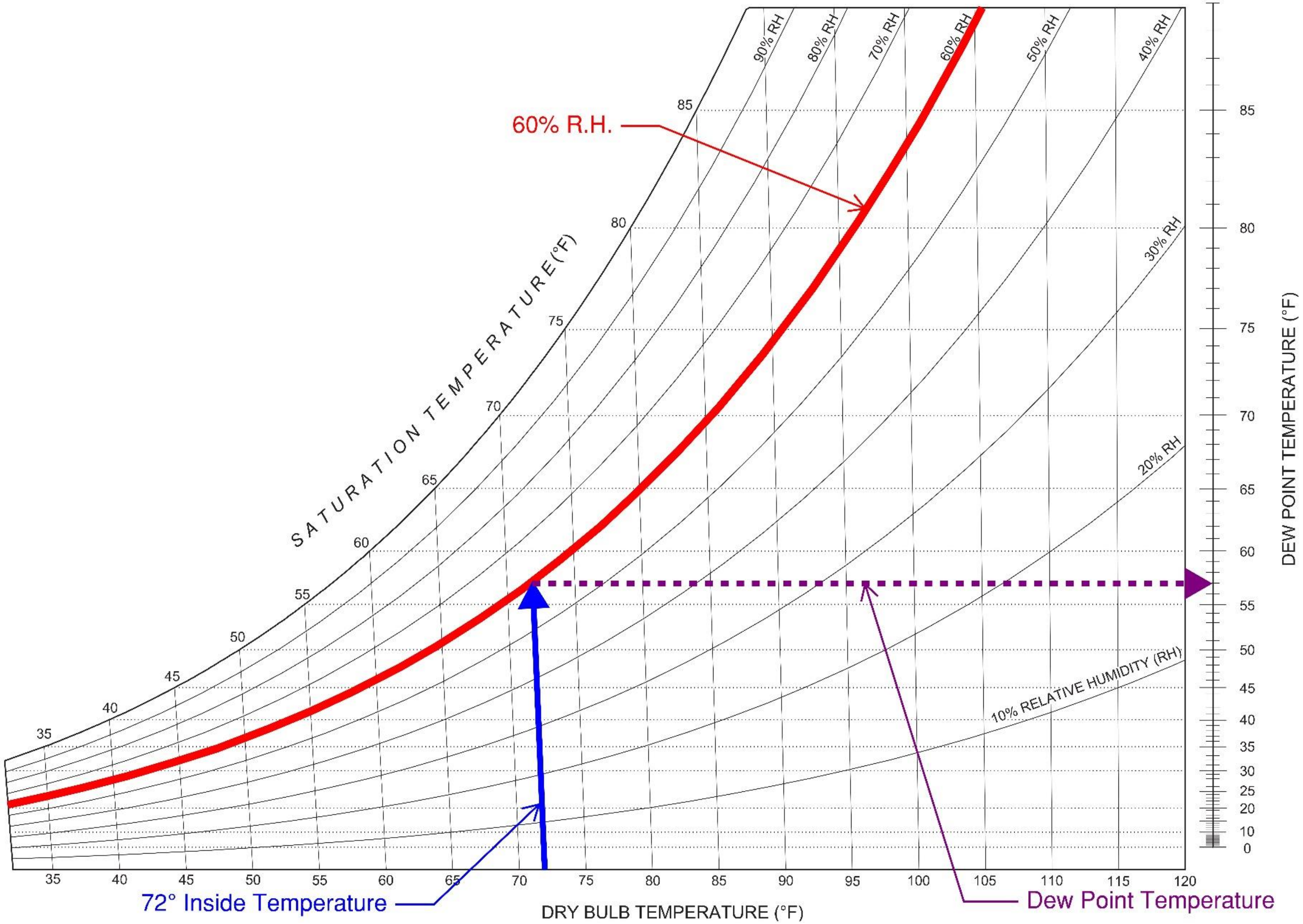
$T_{P1} = 72°\mathrm{F} - \left[\left(\frac{1.17}{33.86}\right)(72°\mathrm{F} - 34°\mathrm{F})\right] = 70.69°\mathrm{F}$

$T_{P2} = 72°\mathrm{F} - \left[\left(\frac{31.17}{33.86}\right)(72°\mathrm{F} - 34°\mathrm{F})\right] = 37.0°\mathrm{F}$

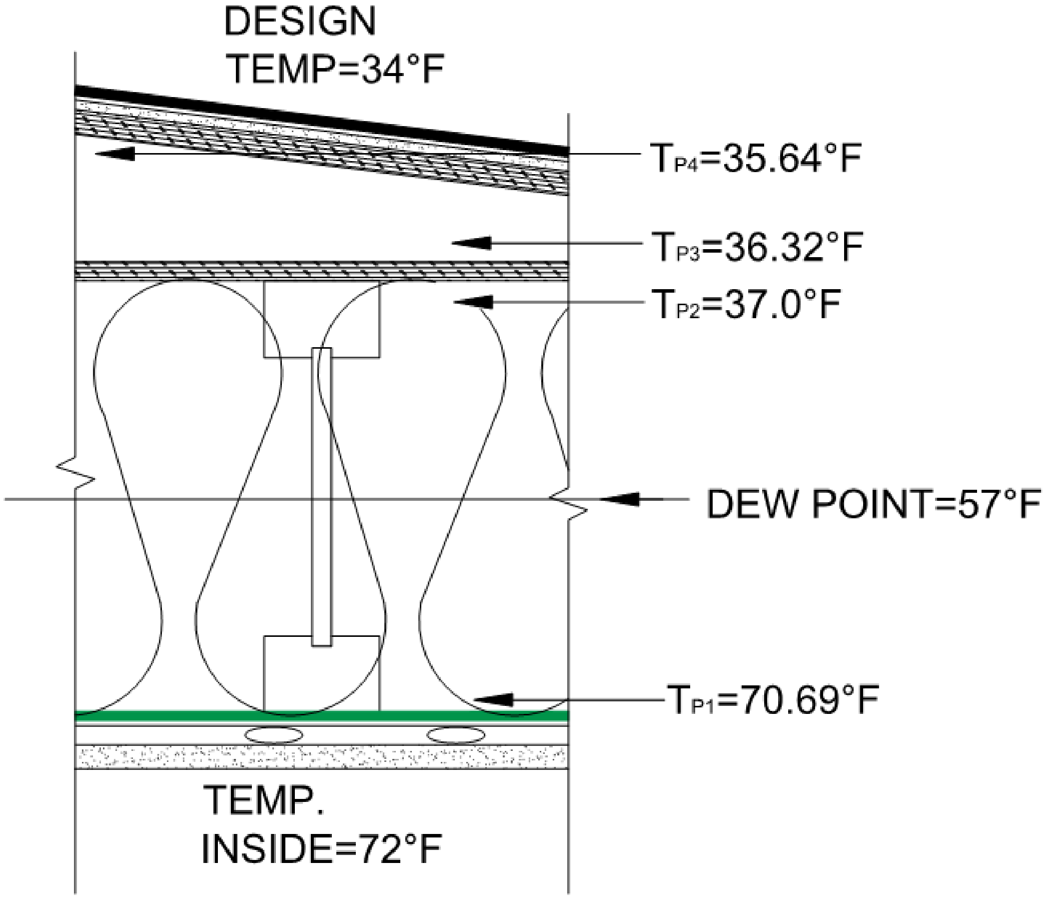
$T_{P3} = 72°\mathrm{F} - \left[\left(\frac{31.79}{33.86}\right)(72°\mathrm{F} - 34°\mathrm{F})\right] = 36.32°\mathrm{F}$

$T_{P4} = 72°\mathrm{F} - \left[\left(\frac{32.4}{33.86}\right)(72°\mathrm{F} - 34°\mathrm{F})\right] = 35.6°\mathrm{F}$

Typical Roof / Ceiling - 1Hr Assembly



Wood Frame Roof – 1-Hr Assembly



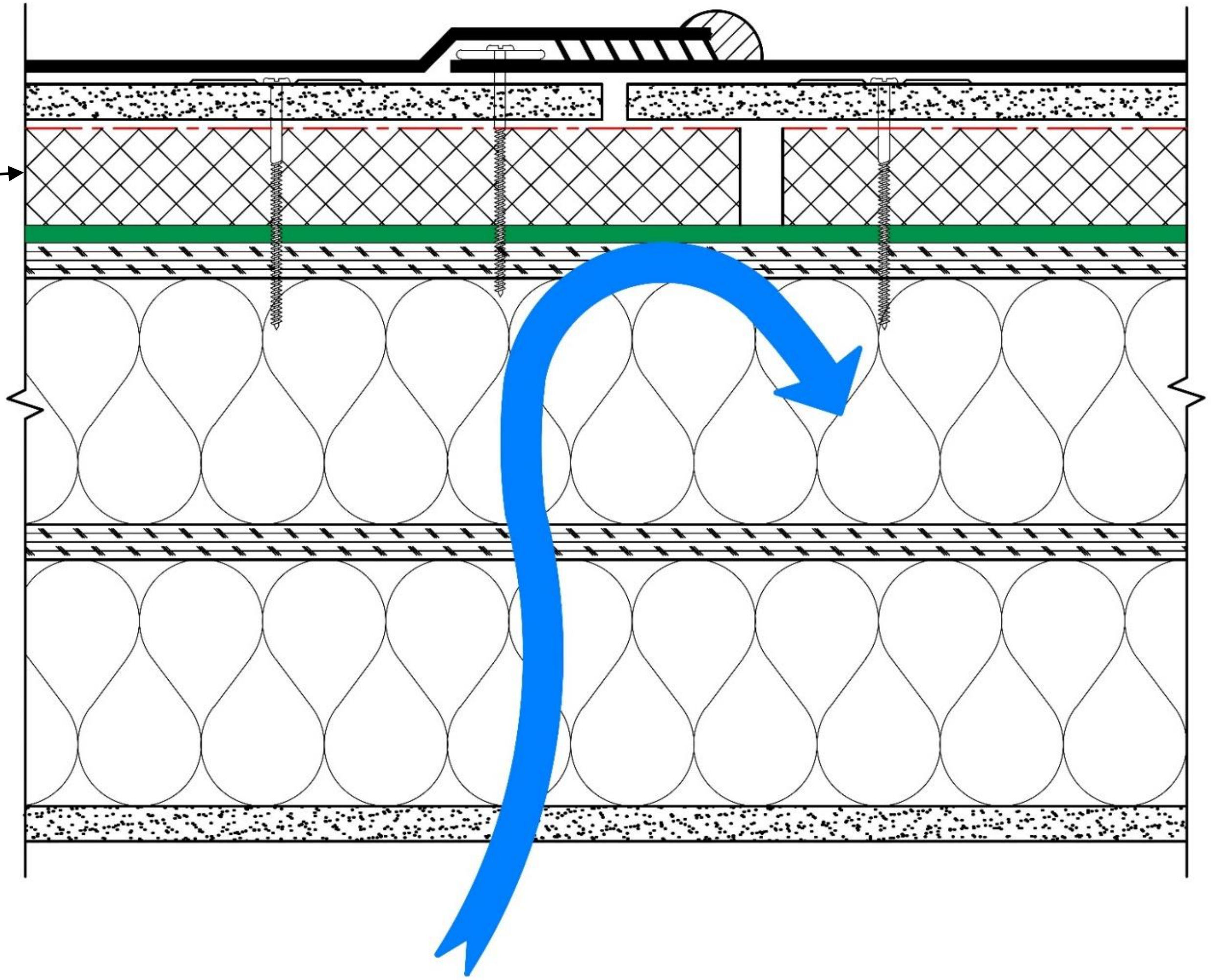
Design Solution – Install a Vapor Retarder

2016 CA Building Code

TABLE 1203.3
INSULATION FOR CONDENSATION CONTROL

CLIMATE ZONE	MINIMUM R-VALUE OF AIR-IMPERMEABLE INSULATION[a]
6-15 tile roof only	0 (none required)
3-15	R-5
1 & 2	R-10
16	R-15

a. Contributes to, but does not supersede, thermal resistance requirements for attic and roof assemblies in the *California Energy Code*.

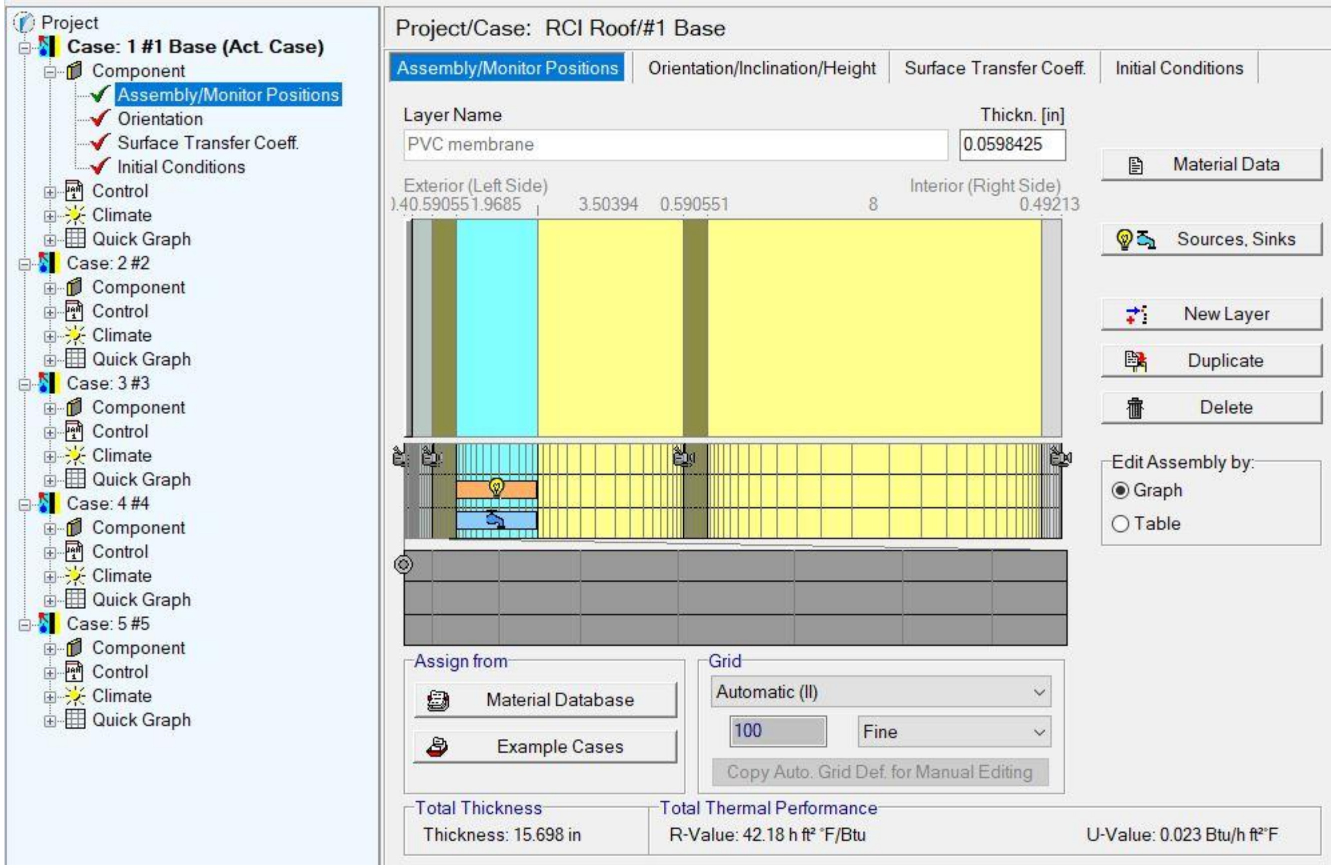


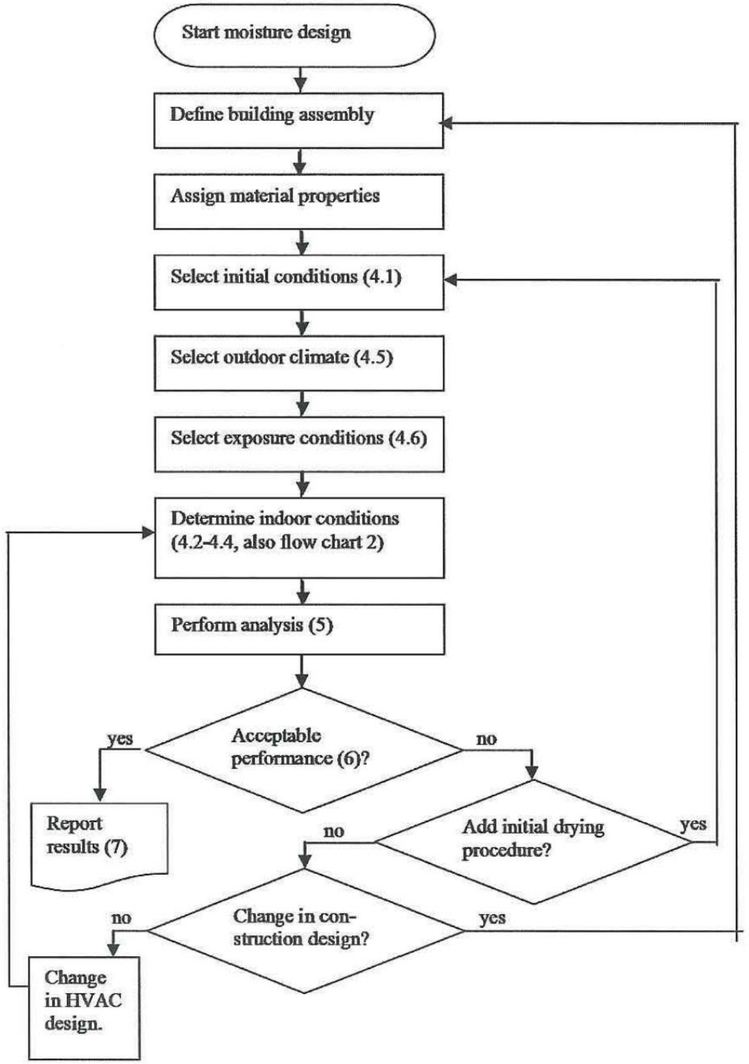
WUFI and ASHRAE

ANSI/ASHRAE Standard 160-2016
(Supersedes ANSI/ASHRAE Standard 160-2009)
Includes ANSI/ASHRAE addenda listed in Annex D

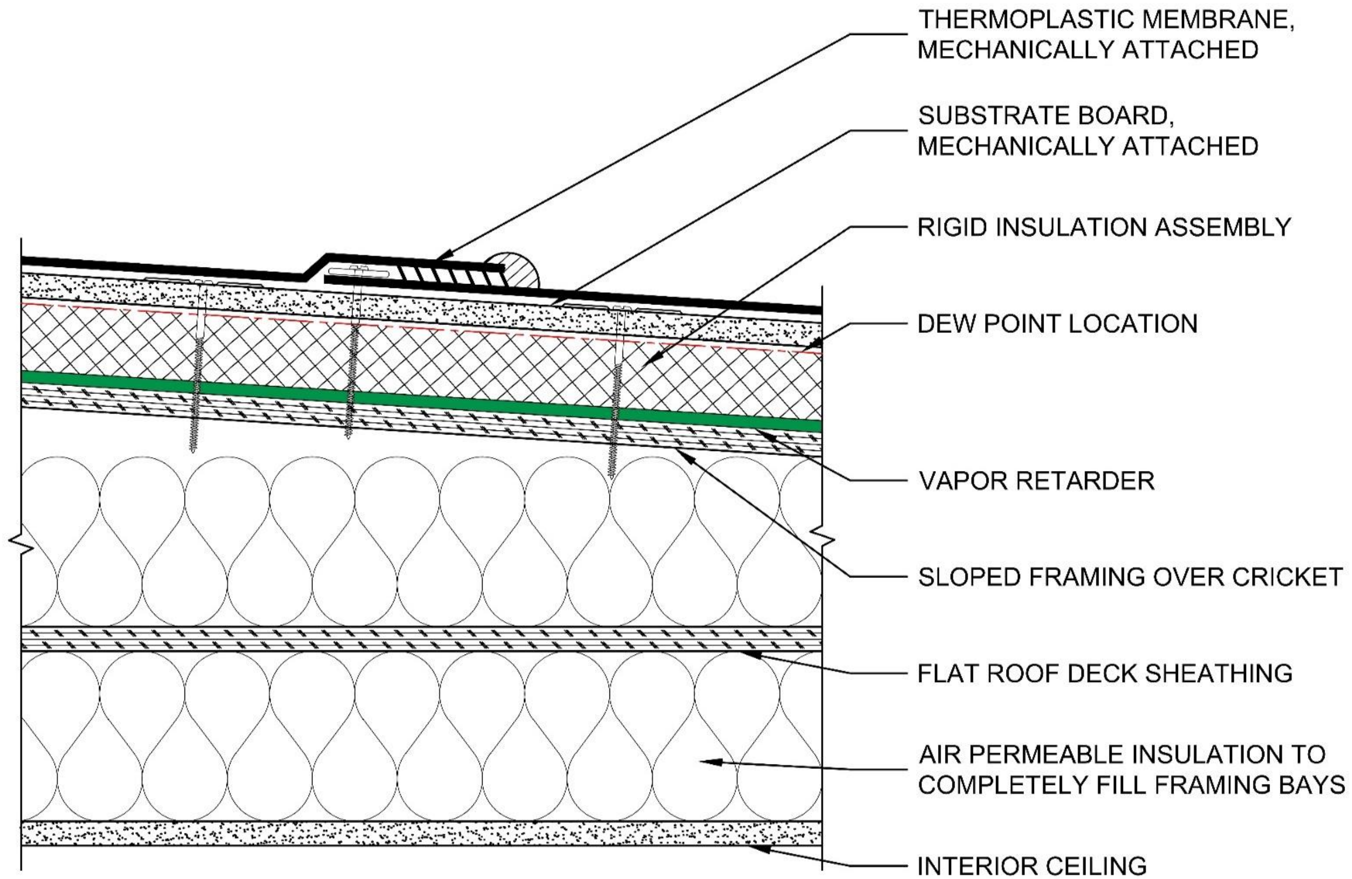
Criteria for Moisture-Control Design Analysis in Buildings

Determining placement of vapor retarder in assembly



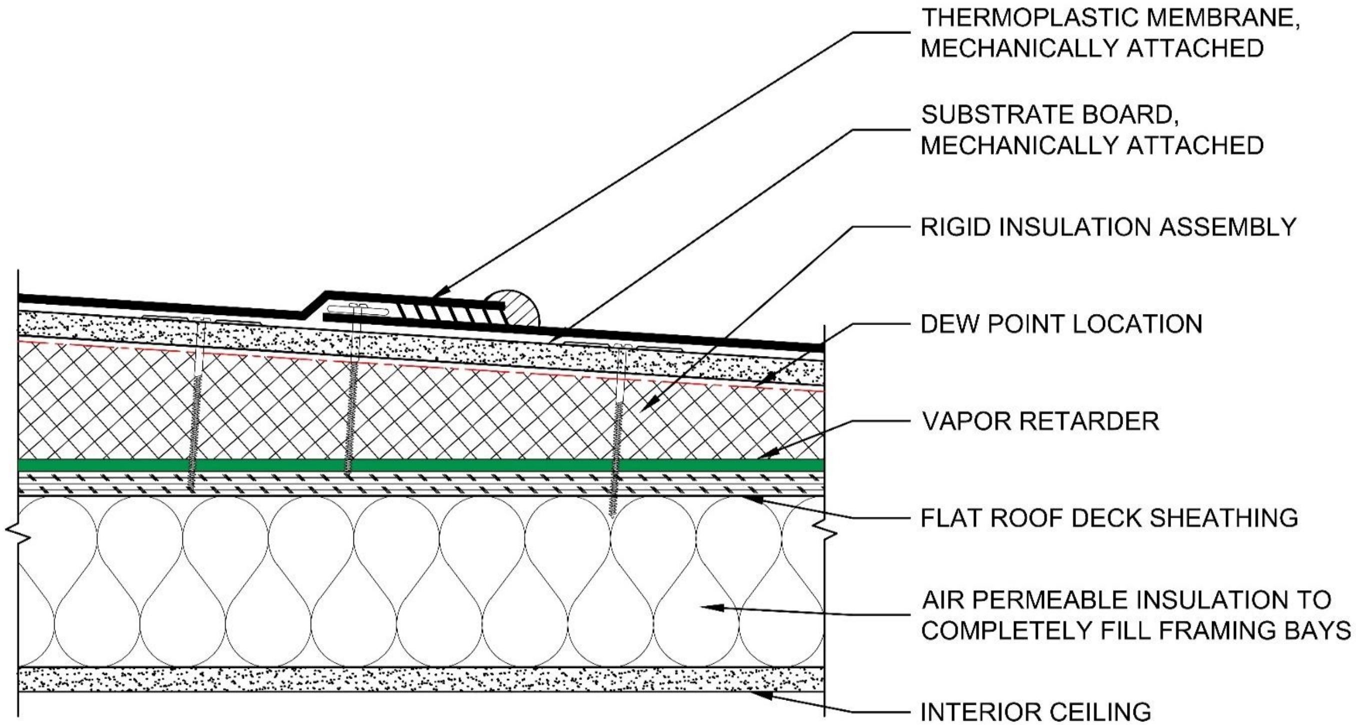


Rigid Insulation with Vapor Barrier



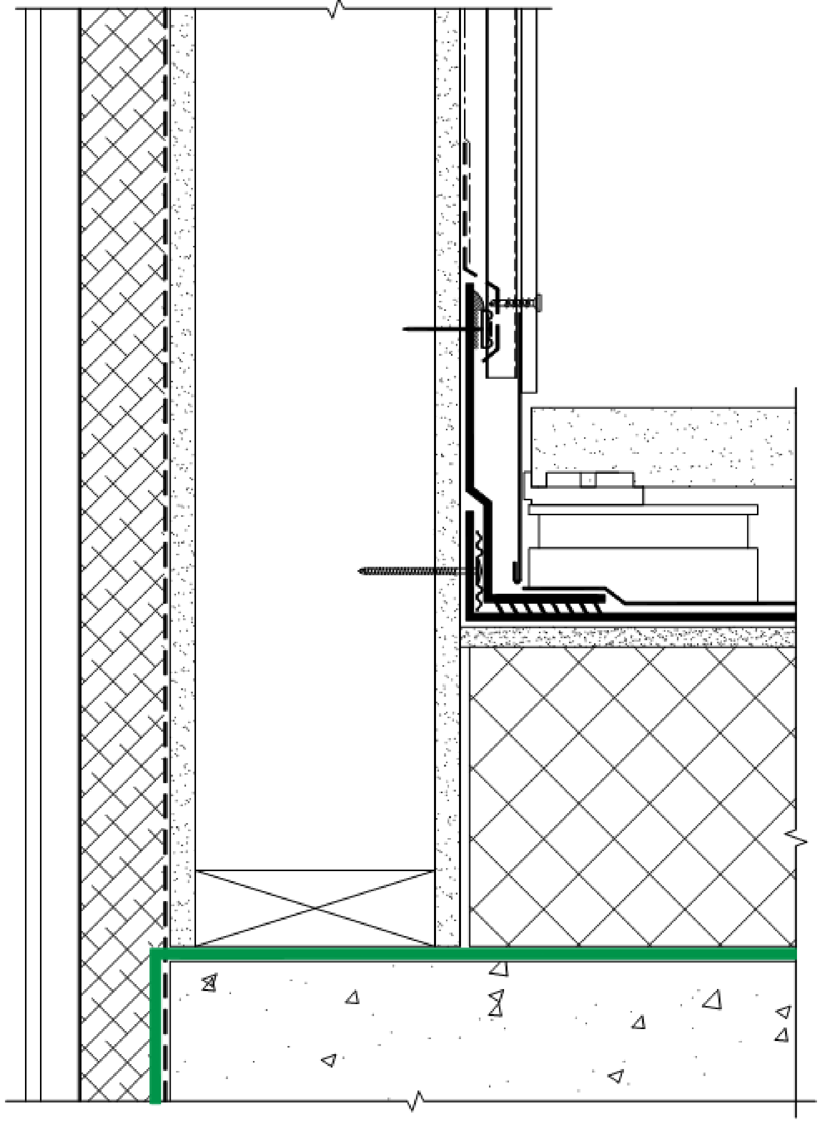
Typical Compact Roof Assembly - Renovation

Rigid Insulation with Vapor Barrier

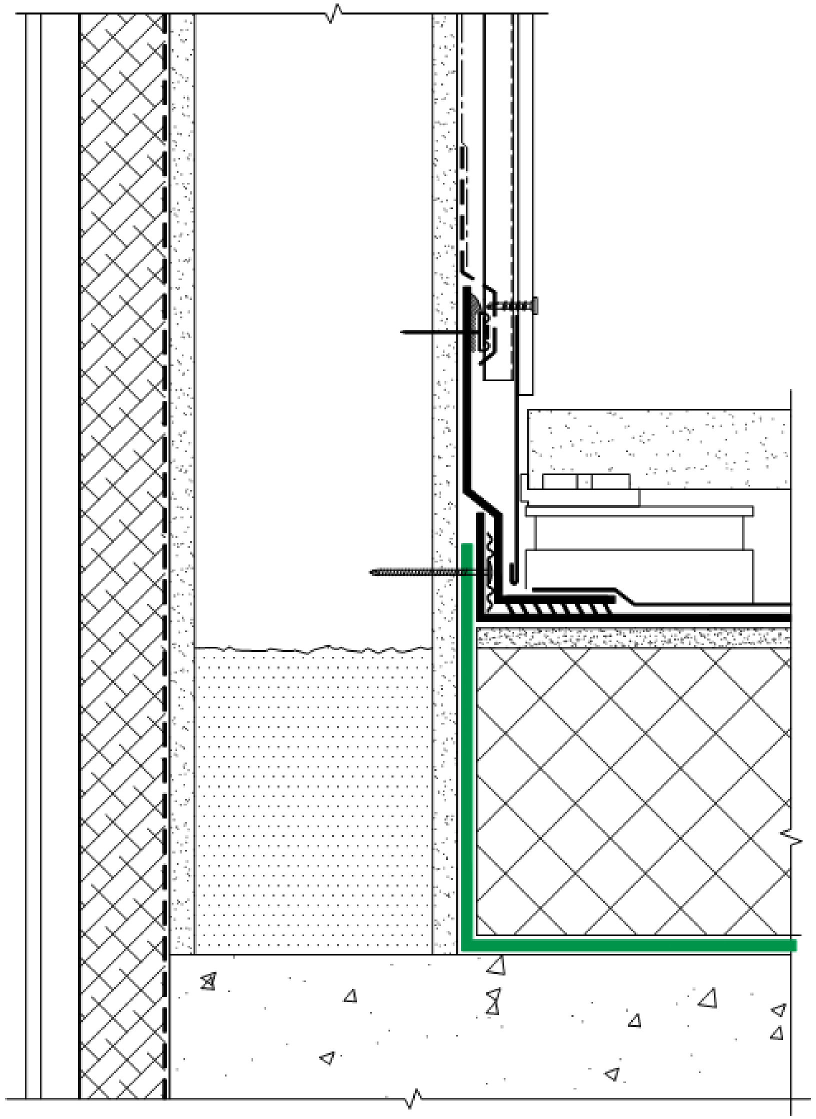


Typical Compact Roof Assembly – New Construction

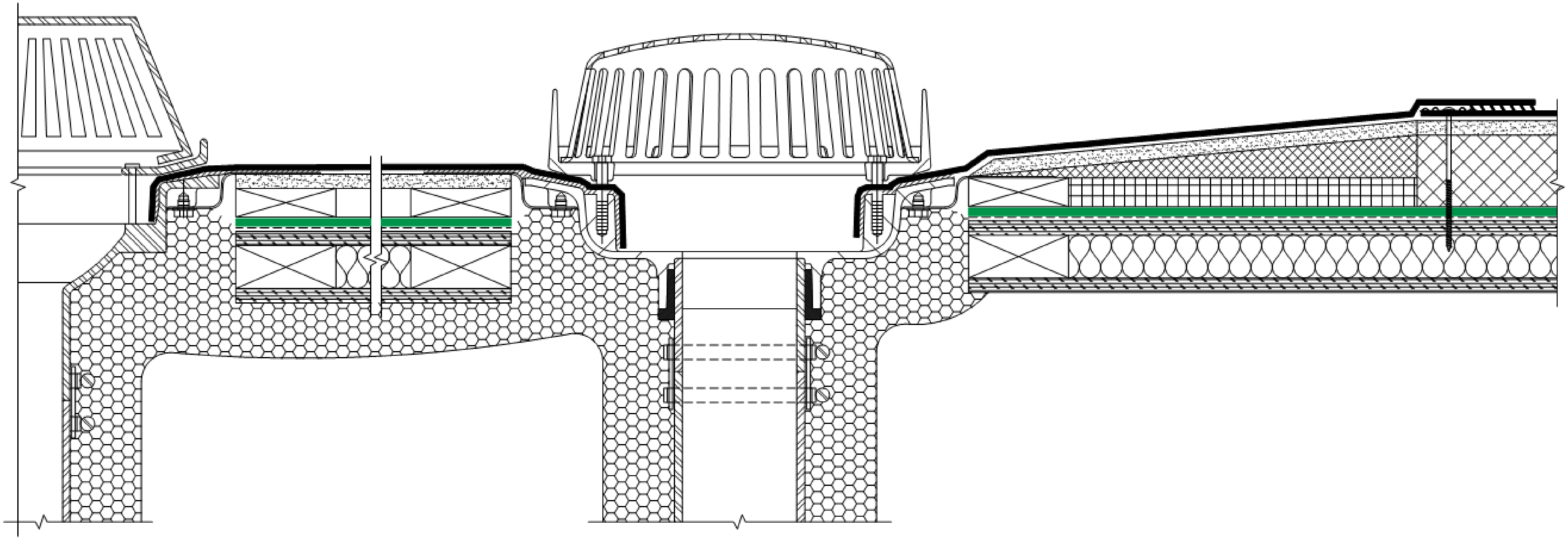
Vapor Retarder Continuity - New Construction



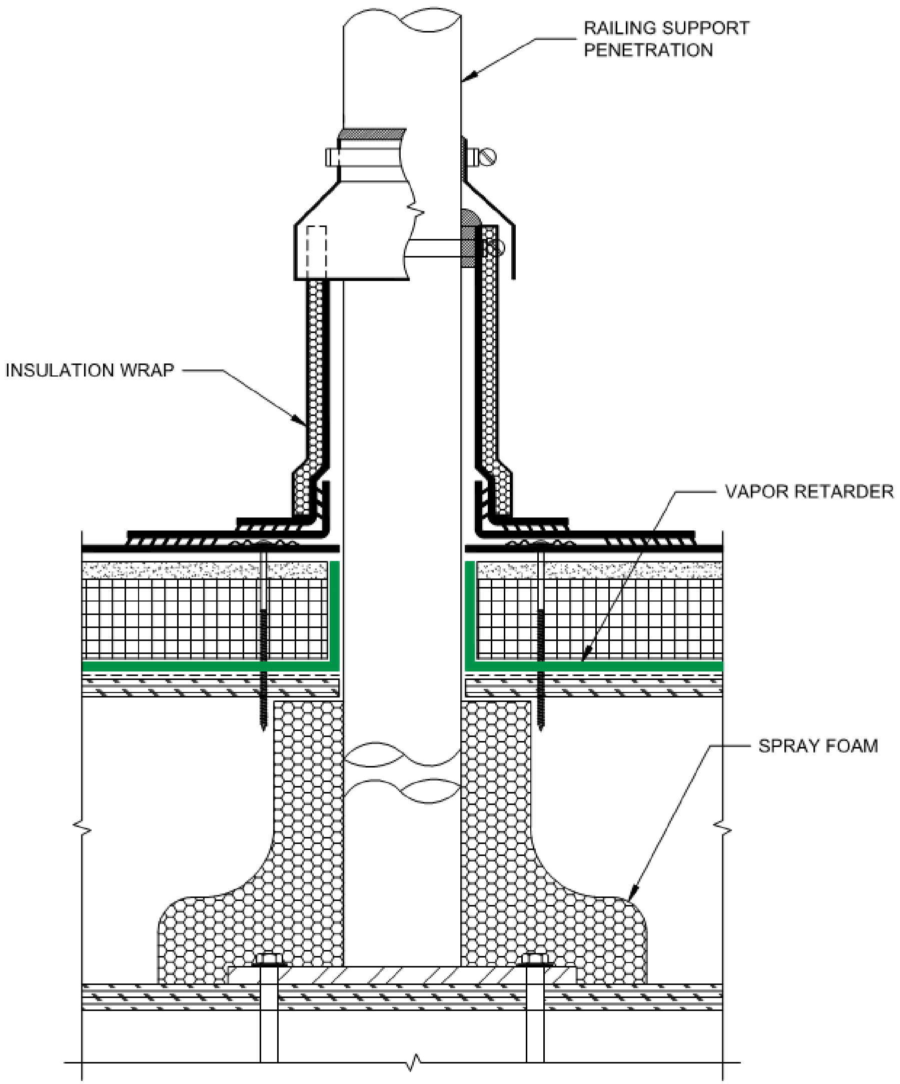
Vapor Retarder Continuity



Vapor Retarder Continuity



Condensation at Penetration



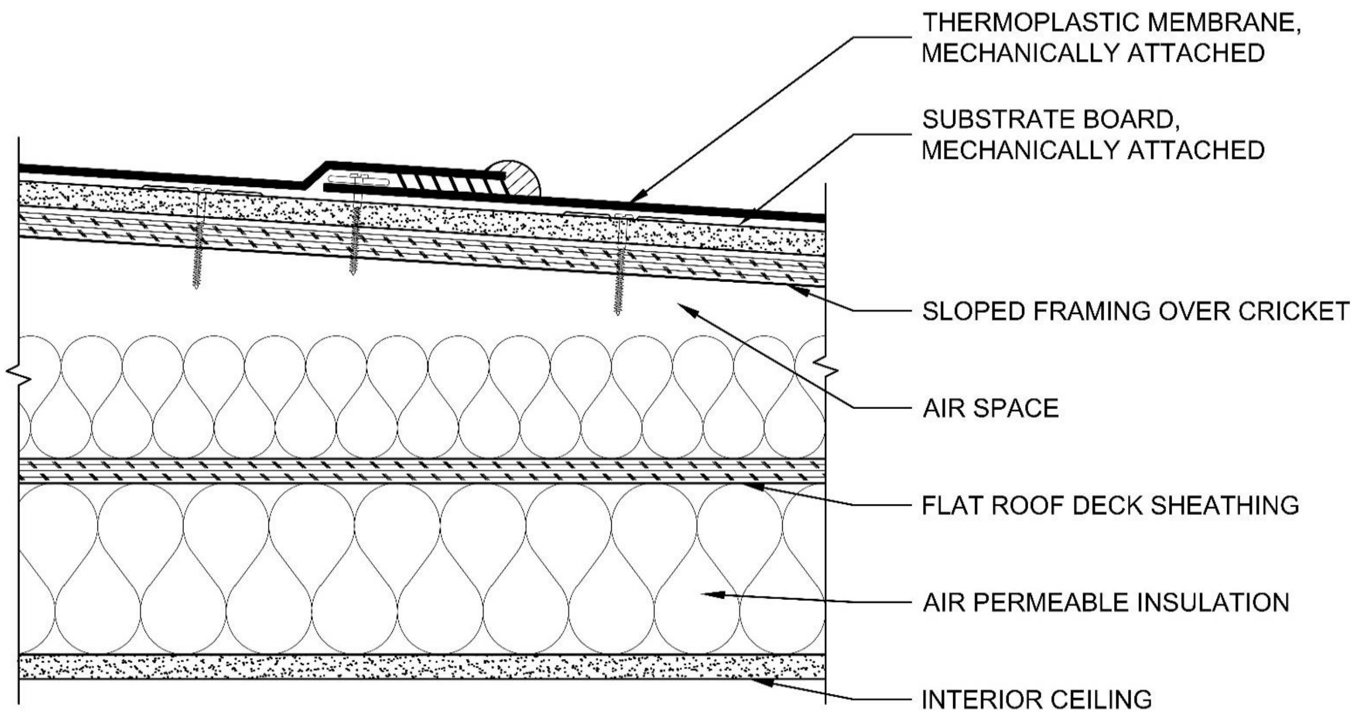
Ventilating Design Options

What is Venting?

- Venting is the exchange of air in enclosed attics, compact roof assemblies, and rafter spaces.

- Passive vs. Active Ventilation
  - Passive ventilation relies on natural air convection to initiate upward flow of air.
  - Active ventilation uses powered fans to initiate flow of air.

Venting Double Roof Deck With Sloped Framing



CBC Code Requirements

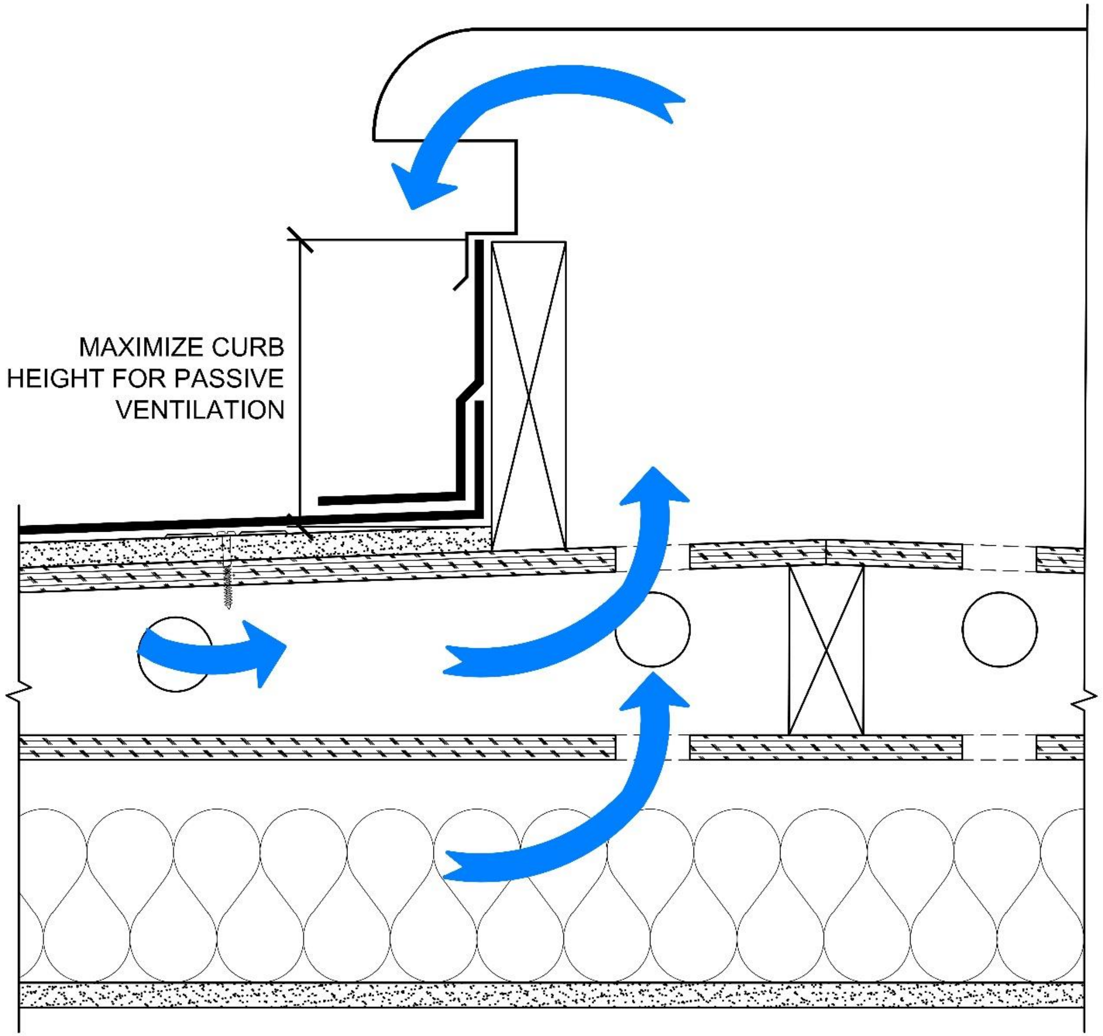
2016 CA Building Code

1203.2 Ventilation required. Enclosed attics and enclosed rafter spaces formed where ceilings are applied directly to the underside of roof framing members shall have cross ventilation for each separate space by ventilation openings protected against the entrance of rain and snow. Blocking and bridging shall be arranged so as not to interfere with the movement of air. An airspace of not less than 1 inch (25 mm) shall be provided between the insulation and the roof sheathing. The net free ventilating area shall be not less than $^1/_{150}$ of the area of the space ventilated. Ventilators shall be installed in accordance with manufacturer's installation instructions.

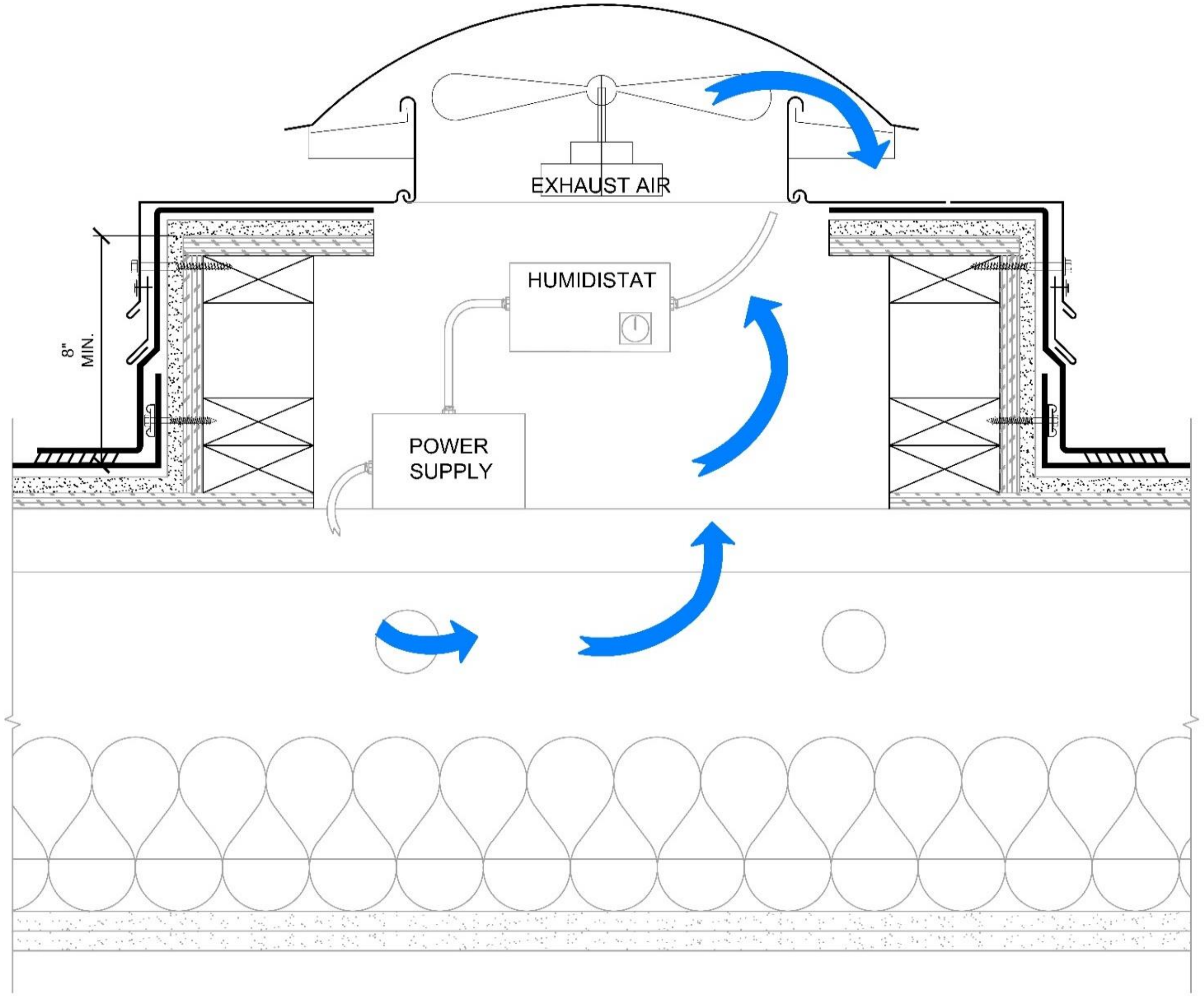
Exception: The net free cross-ventilation area shall be permitted to be reduced to $^1/_{300}$ provided both of the following conditions are met:

1. In Climate Zones *14 and 16*, a Class I or II vapor retarder is installed on the warm-in-winter side of the ceiling.
2. At least 40 percent and not more than 50 percent of the required venting area is provided by ventilators located in the upper portion of the attic or rafter space. Upper ventilators shall be located not more than 3 feet (914 mm) below the ridge or highest point of the space, measured vertically, with the balance of the ventilation provided by eave or cornice vents. Where the location of wall or roof framing members conflicts with the installation of upper ventilators, installation more than 3 feet (914 mm) below the ridge or highest point of the space shall be permitted.

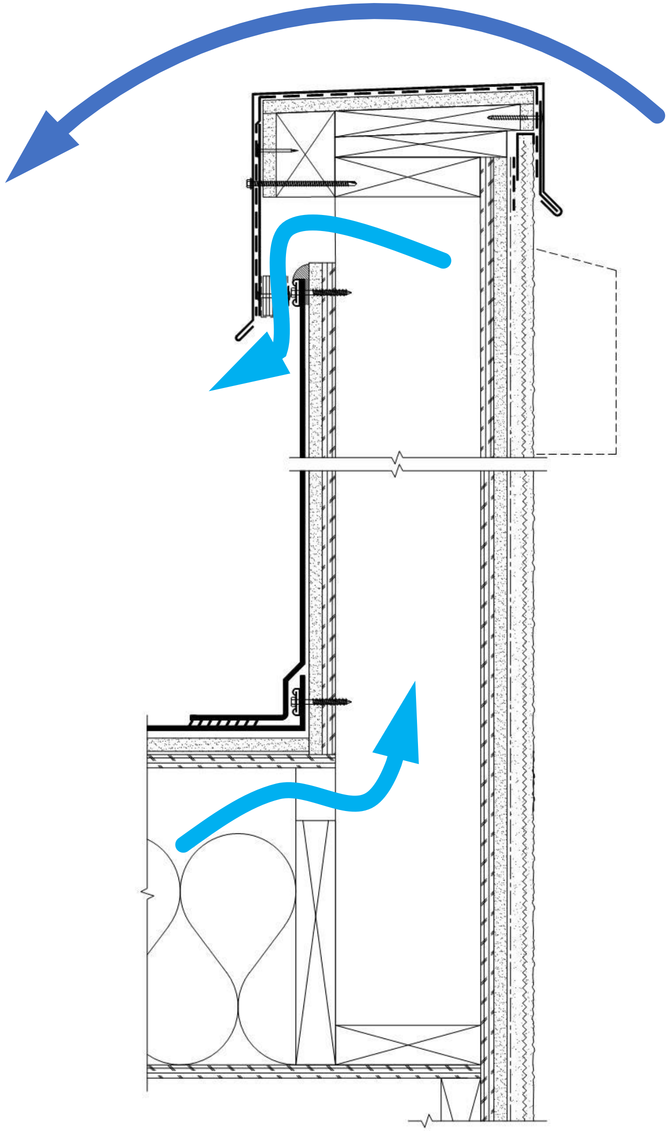
Venting Double Roof Deck With Sloped Framing



Power Ventilation



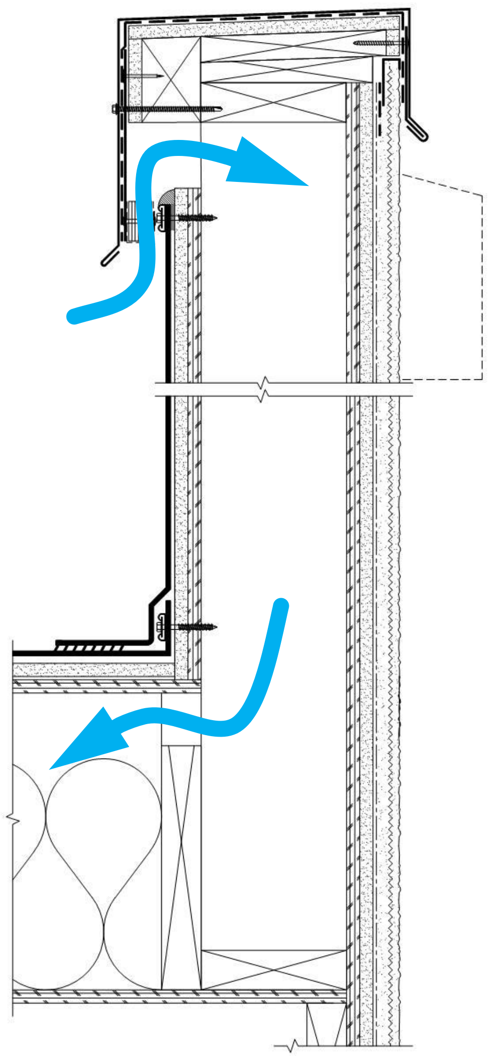
Venting Double Roof Deck With Sloped Framing



Air flow over the parapet creates negative pressure on the inside of the parapet, pulling air from the assembly.

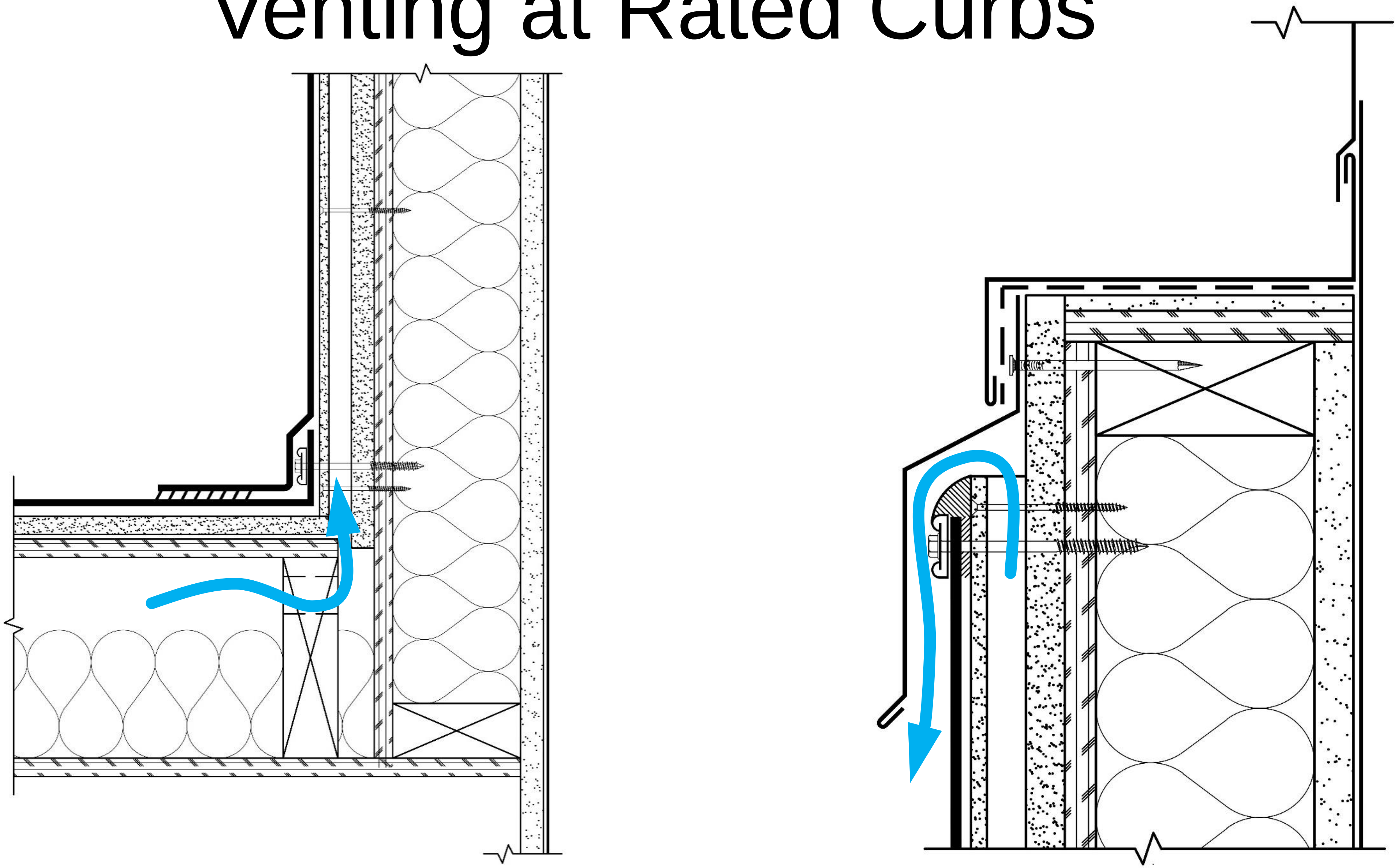
Passive Ventilation

Venting Double Roof Deck With Sloped Framing

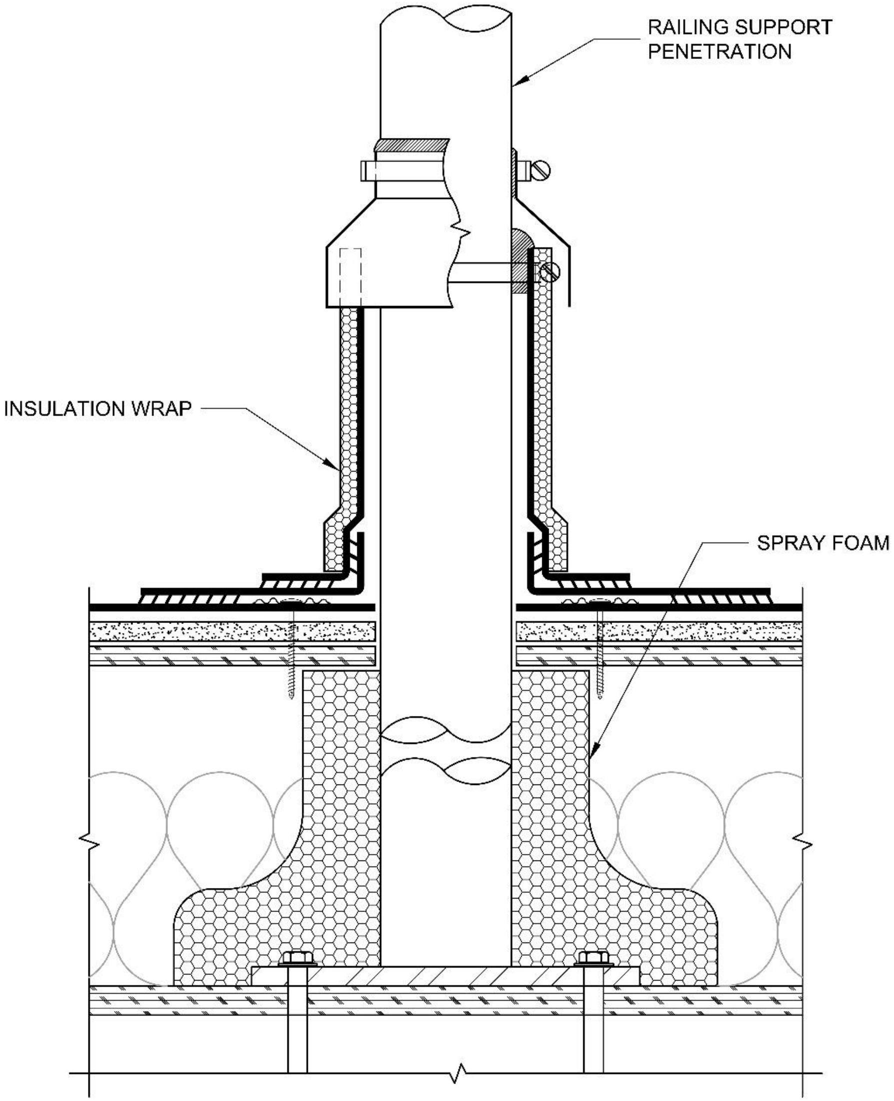


Mechanical
Ventilation

Venting at Rated Curbs



Condensation at Penetrations



Summary of Vapor Retarder Options

- Determine Need
  - Consider climate zone and building usage.

- Select the Correct Product
  - Consider material permeance.
  - Consider detailing requirements and puncture\tear resistance.
  - Evaluate benefits of vapor retarder as a temporary roof.

- Define the Assembly
  - Design and model assembly to control dew point location.

- Detail, Continuity, and QA/QC

Summary of Venting Options

- Determine Need
  - Venting is required by the building code, unless design is for an unvented attic/unvented enclosed rafter assembly per CBC 1203.3.

- Select the Correct Type
  - Passive Ventilation: Difficult to achieve within complex roof configurations; air may introduce moisture rather than remove it.
  - Active Ventilation: Effective air exchange management using humidistat.

- Design Ventilation
  - Provide adequate intake (at low side) and exhaust (at high side).
  - Provide cross ventilation between framing bays.
  - Provide adequate venting cavity space, 2” minimum.

Questions and Answers

Thank You!