



33RD RCI INTERNATIONAL CONVENTION & TRADE SHOW

Envision the Future

Building Envelope Consulting : Roofing | Waterproofing | Exterior Walls

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Houston, Texas

Avoiding Condensation in Low-Slope Roofing Assemblies

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and*

Robert Worthing, CDT

Allana Buick & Bers, Inc.



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Making Buildings Perform Better



Best Practice

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Karim P. Allana, PE, RRC, RWC

- **Education:** B.S., Civil Engineering, Santa Clara University
- **Registration:** P.E., Civil Engineering, California, Washington, Nevada, and Hawaii
- **Certification:** Registered Roof Consultant (RRC), Roof Consultants Institute, and Registered Waterproofing Consultant (RWC)
- **Overview:**
 - CEO and Senior Principal at Allana Buick & Bers.
 - Former Turner Construction Employee (Project Engineering and Superintendent)
 - Over 37 years experience providing superior technical standards in all aspects of building technology and energy efficiency.
 - Principal consultant in forensic investigations of building assemblies, failure analysis, evaluation and design of building infrastructure and building envelope evaluation and design.
 - Expert in all aspects of building envelope technology.
 - Completed numerous new construction, addition, rehabilitation, remodel and modernization projects for public and private sector clients.
 - Specialization in siding, roofing, cement plaster, wood, water intrusion damage, window assemblies, storefronts, below grade waterproofing, energy efficiency, solar engineering and complex building envelope and mechanical assemblies.



ABBAE Firm Overview

- Allana Buick & Bers (ABBAE) is an Architectural Engineering firm specializing in Building Envelope Systems
- ABBAE is one of the 5 largest building envelope consultants in the country
- ABBAE has over 33 years of experience & over 12,500 projects
- ABBAE is also a leading Forensic Defect firm with hundreds of forensic projects (litigation)
- Locations – 16 offices across California, Nevada, North Carolina, Oklahoma, Oregon, Texas, Virginia, Washington, Colorado and Hawaii



Staff & In-House Expertise

- Licensed Professional Engineers – Civil, Structural, and Mechanical
- Registered Architects
- Building Enclosure Commissioning Process Providers (BECxPs)
- Registered Building Envelope Consultant (RBEC)
- Registered Roofing Consultants (RRCs)
- Registered Waterproofing Consultants (RWCs)
- Registered Exterior Wall Consultant (REWCs)
- Registered Roof Observers (RROs)
- Certified Exterior Insulation and Finish System (EIFS) inspectors
- Curtain Wall Specialists
- ICC Certified Building Inspectors
- Quality Assurance Monitors
- Water Testing Experts
- Leak Investigation and Diagnosis Experts
- Infrared Imaging and Nuclear Moisture Scanning Experts



ABBAAE Building Expertise

- Building Envelope Systems
 - Roofing Systems
 - High-Slope/Low-Slope Roofs
 - Green/Garden Roofs
 - Drainage Systems
 - Pedestrian Plazas
 - Exterior Wall Systems
 - Wall Cladding/Siding/GFRC/pre-cast
 - EIFS/cement plaster/stucco
 - Sheet Metal Flashings
 - Windows and Glazing Systems
 - Punched Windows
 - Curtain Wall/Window Wall Systems
 - Sliding Glass Doors
 - Skylights
- Building Envelope Systems (cont'd)
 - Roofing & Waterproofing Systems
 - Deck/Balcony/Lanai Waterproofing
 - Podium Waterproofing
 - Pool/Spa Deck Waterproofing
 - Above-Grade/Below-Grade Waterproofing
 - All types of low and steep sloped roofing
 - Commissioning BECx
 - OPR/BOD/Commissioning Plan
- Mechanical/HVAC Systems
 - HVAC design
 - Plumbing systems
 - Commissioning and testing



ABBAE Core Services

- Consulting and third-party peer review services
- Engineer of record for building envelope systems
- Contract administration services
- Inspection services (usually direct with owner)
- Air and water performance testing
- Mock-up design, observation, and testing
- Building assessments and forensic investigations
- Litigation support and expert witness services
- Educational seminars with AIA credits



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



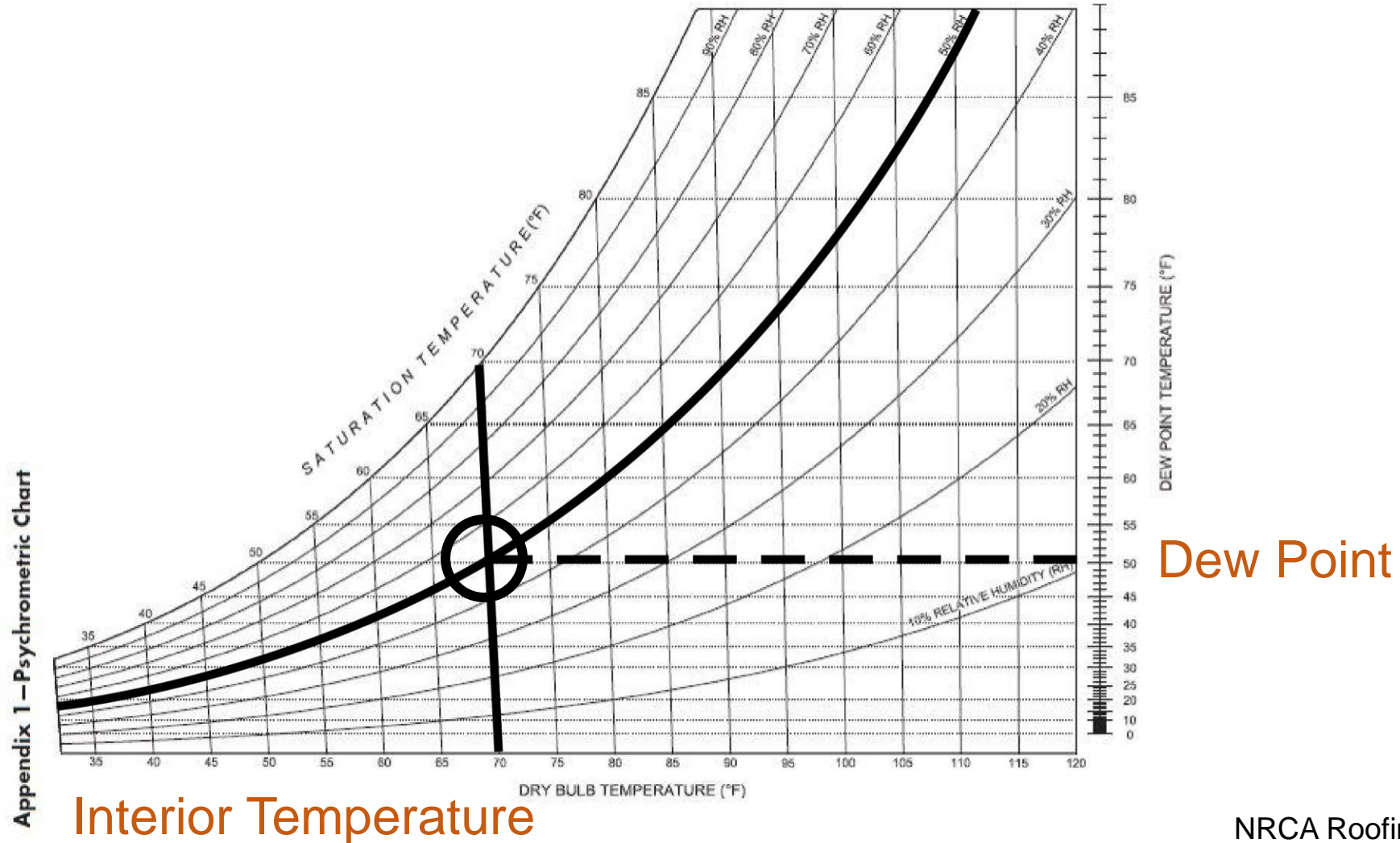
Condensation

- When air containing moisture cools, some of the moisture condenses into liquid water
- The temperature at which this occurs is called the dew point



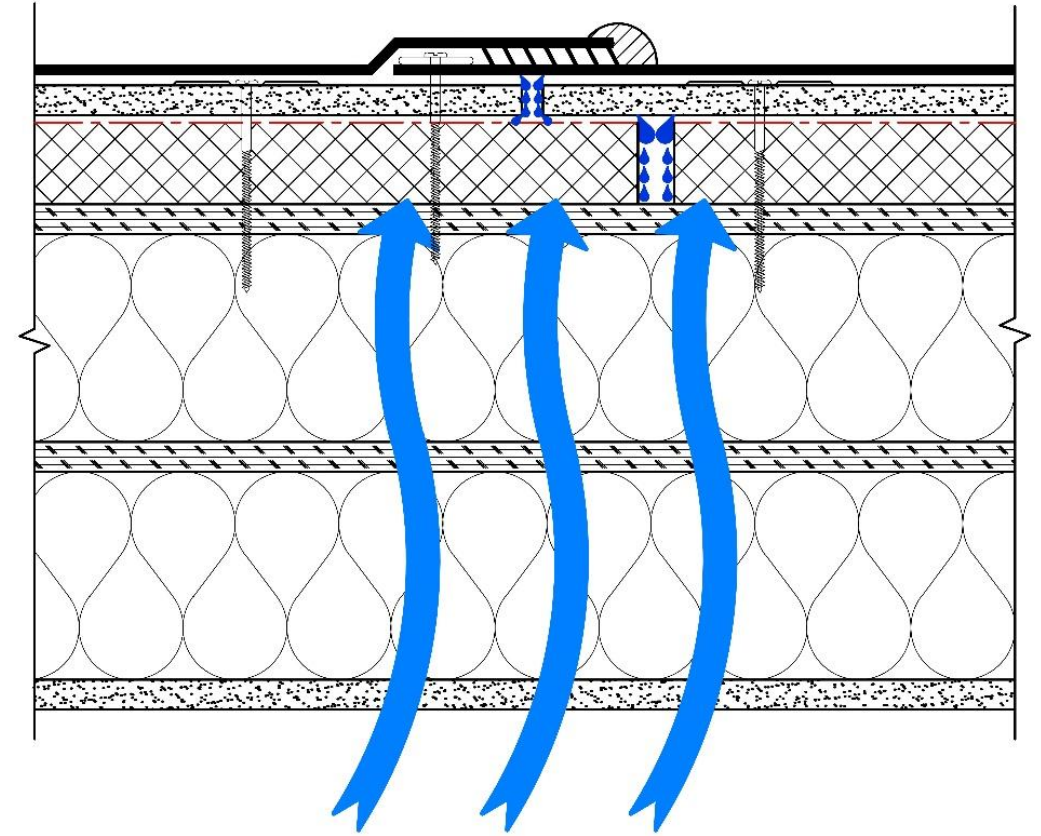
Psychrometric Chart

Interior RH %

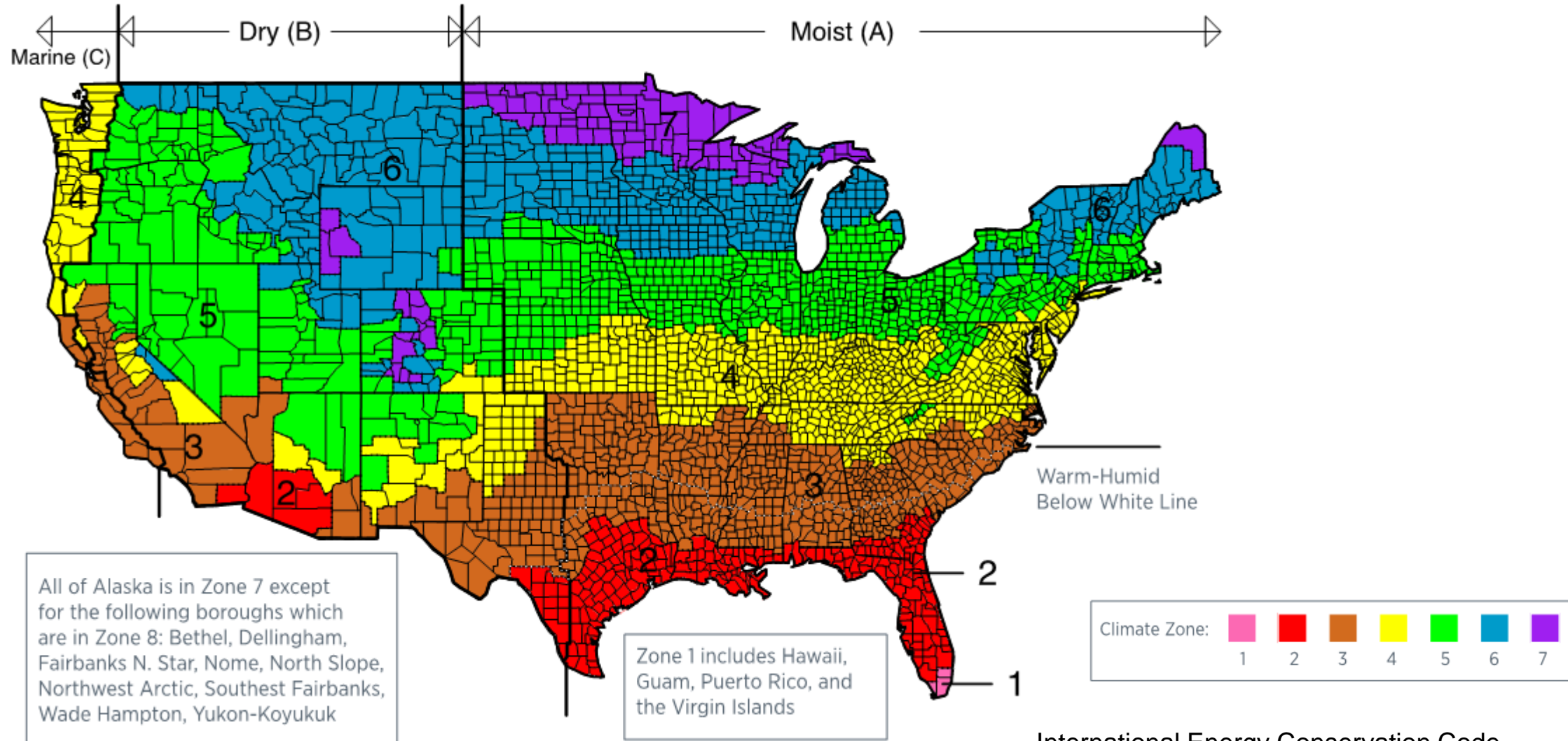


Condensation in Roof Assemblies

- 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

ALASKA HAS AN AVERAGE JANUARY
TEMPERATURE BELOW 40°F



HAWAII DOES NOT HAVE AN AVERAGE
JANUARY TEMPERATURE BELOW 40°F

Combined
with an
anticipated
interior RH of
45% or Higher



REGION OF THE U.S. WITH AN AVERAGE JANUARY
TEMPERATURE BELOW 40°F. CONTOURS REPRESENT
U.S. CLIMATE DIVISIONS.



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

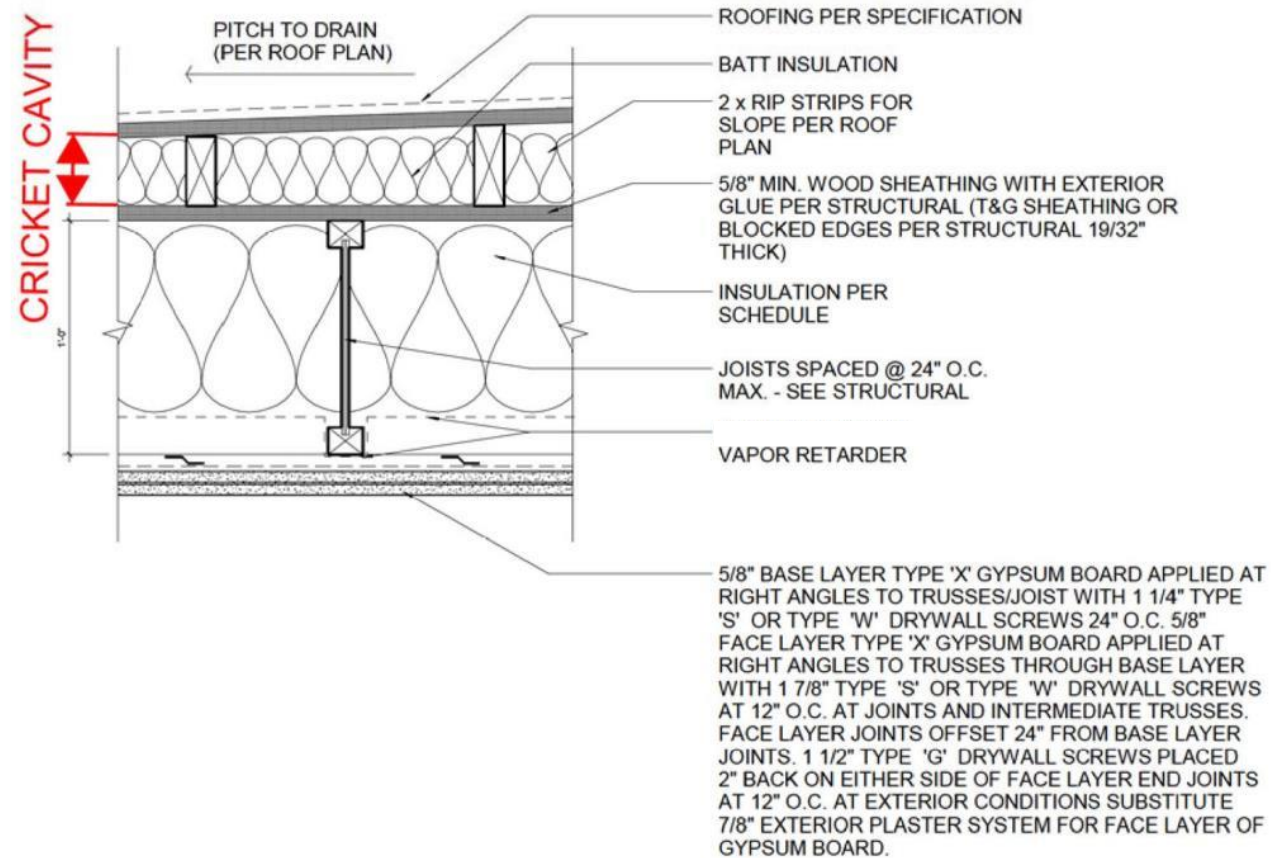


Building Usage and Construction

- 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 groove 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

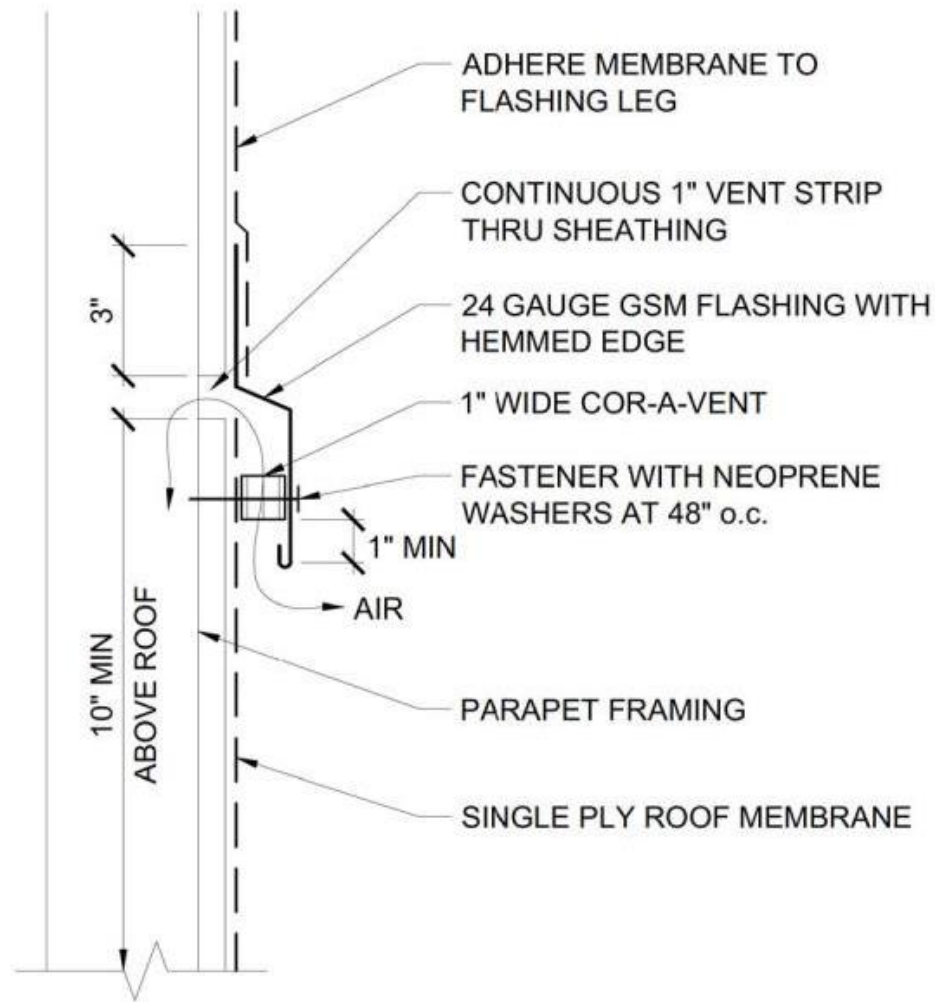


TYPICAL ROOF / CEILING

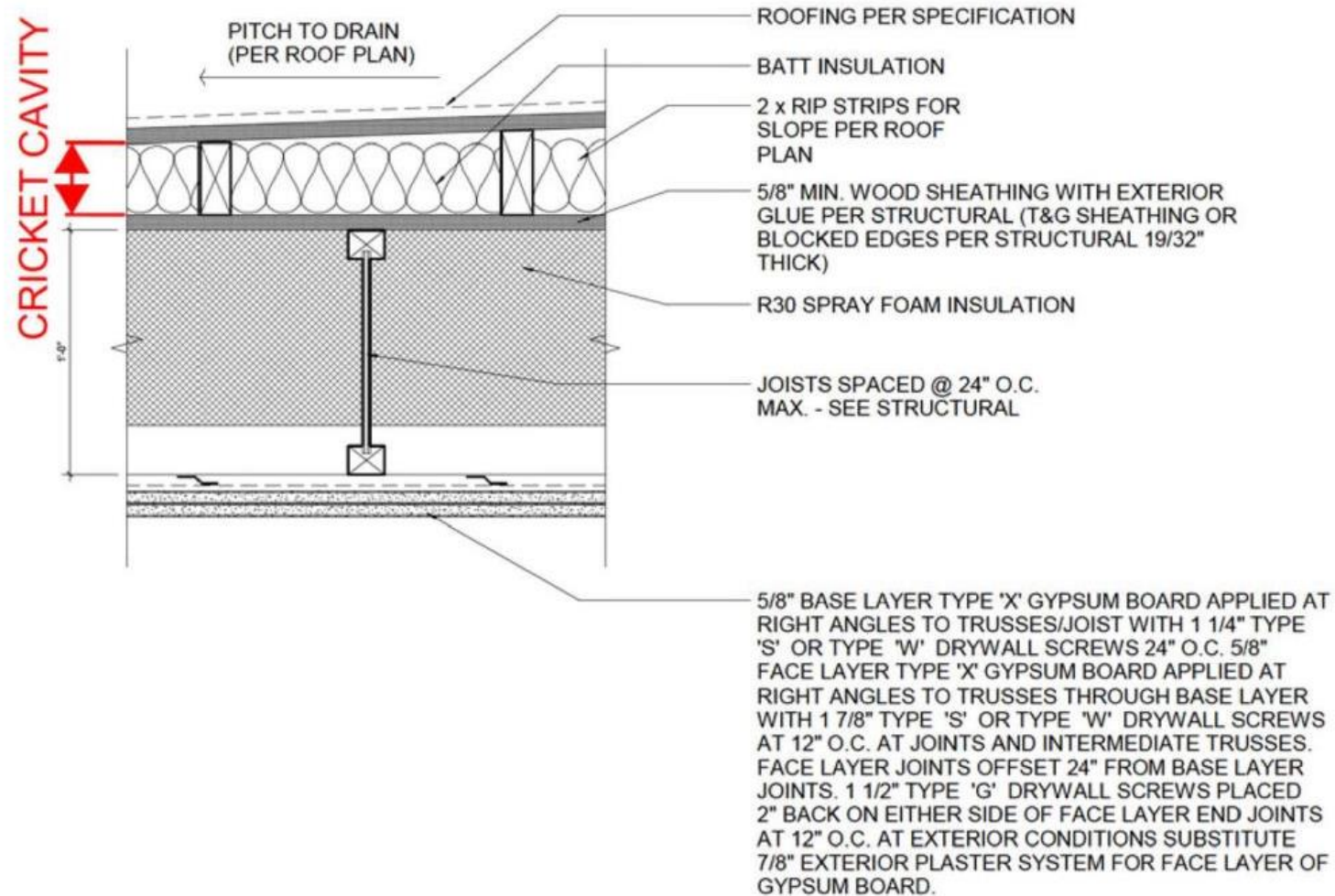
3"=1'-0"



Architect's Option 2 For Condensation Control

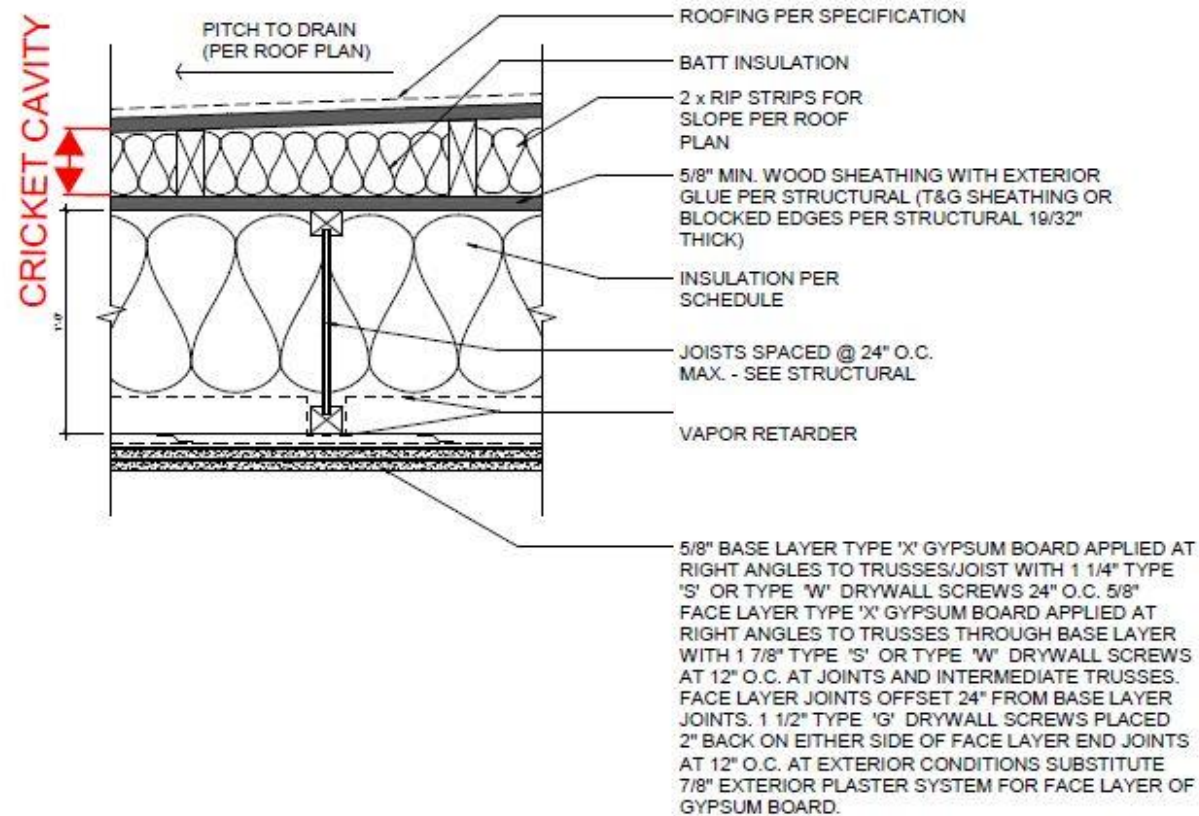


Architect's Option 3 For Condensation Control



Selected Option for Condensation Control

Roof Assembly Per Plans



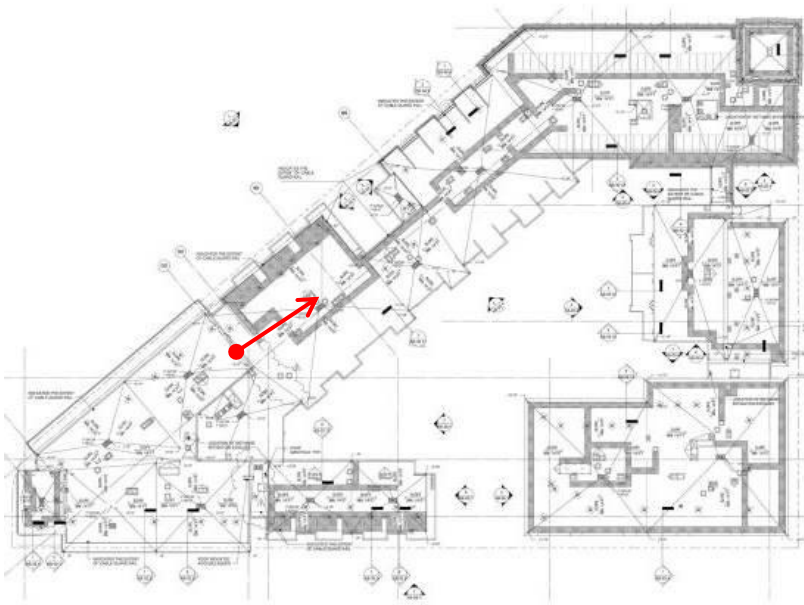
TYPICAL ROOF / CEILING

3"=1'-0"



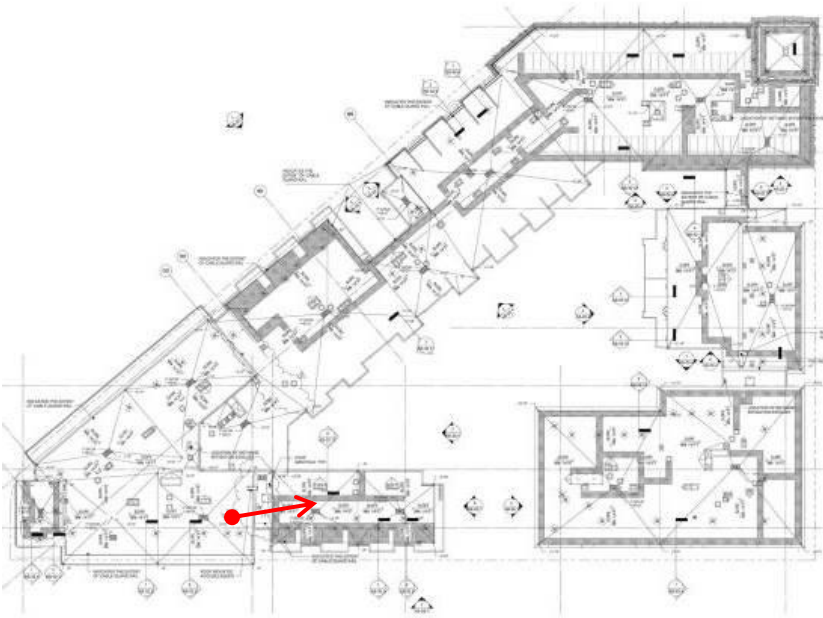
Roof Overall Photos

Looking northeast from
Level 6 roof upper area

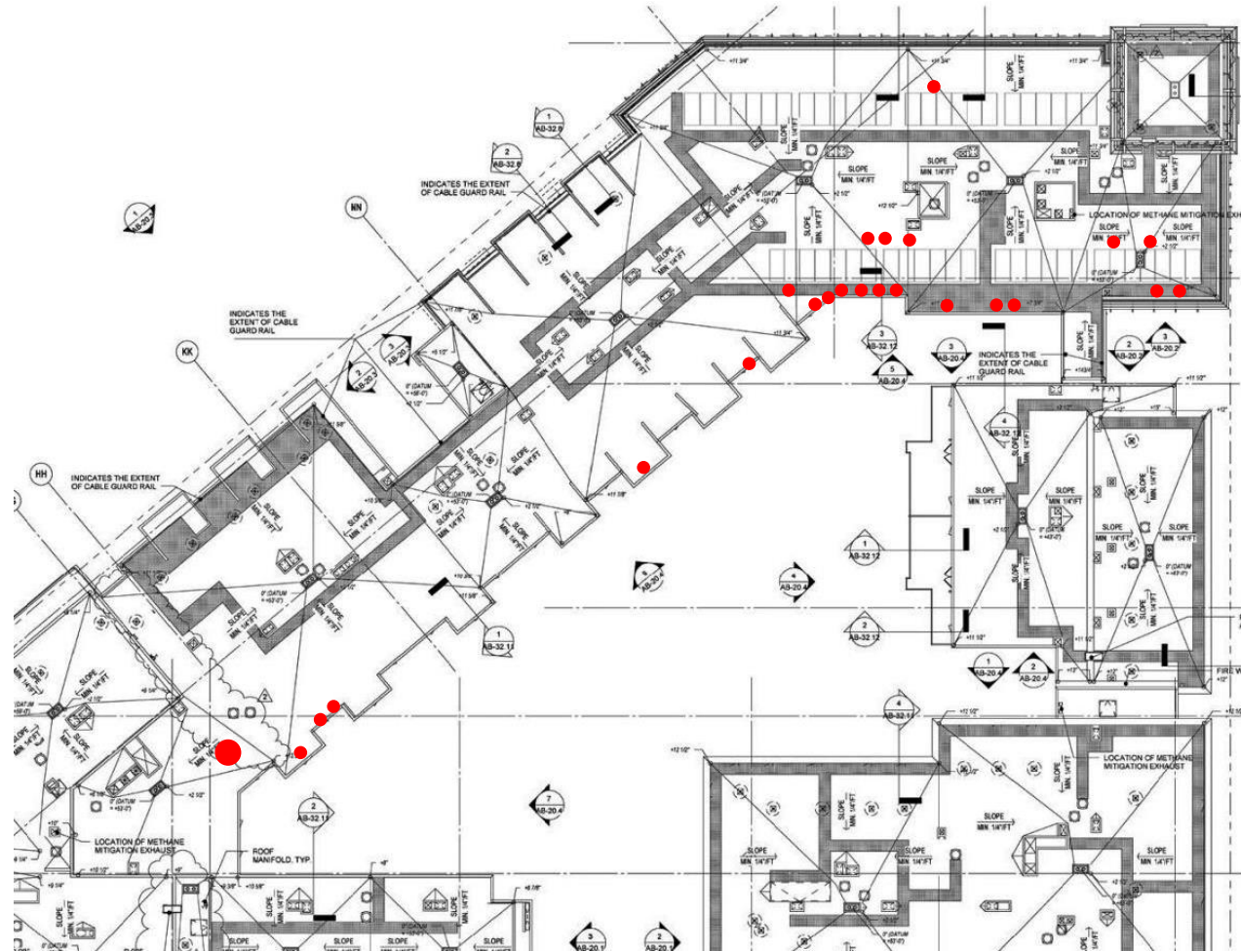


Roof Overall Photos

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



A photograph of a construction site floor, likely concrete, showing two circular metal grates in the foreground. In the background, there is surveying equipment, including a yellow level and a metal tripod. The text "Non-Destructive Testing and Survey" is overlaid in the center.

Non-Destructive Testing and Survey



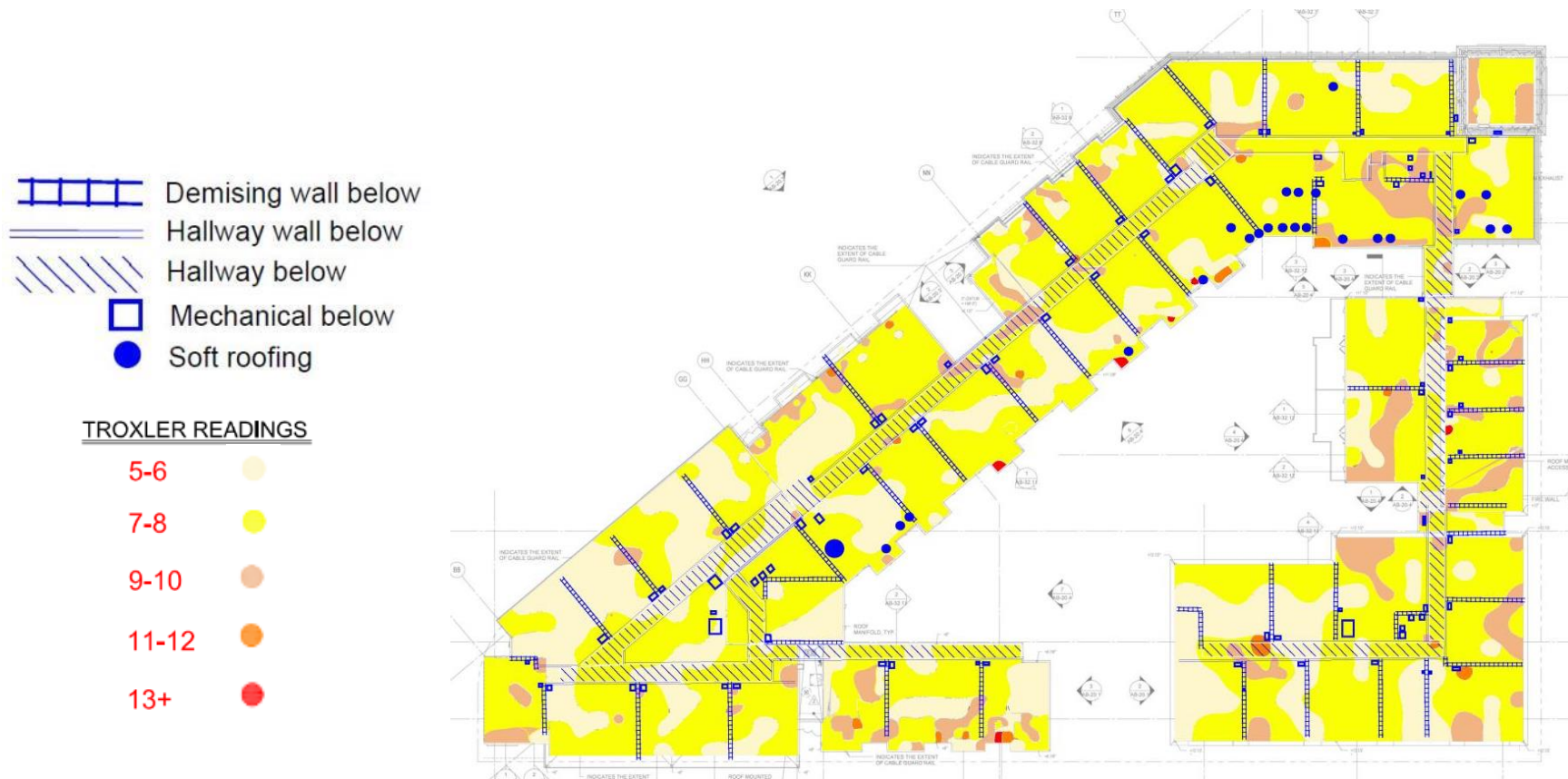
Non-Destructive Nuclear Gauge Equipment



Non-Destructive Electrical Impedance Equipment



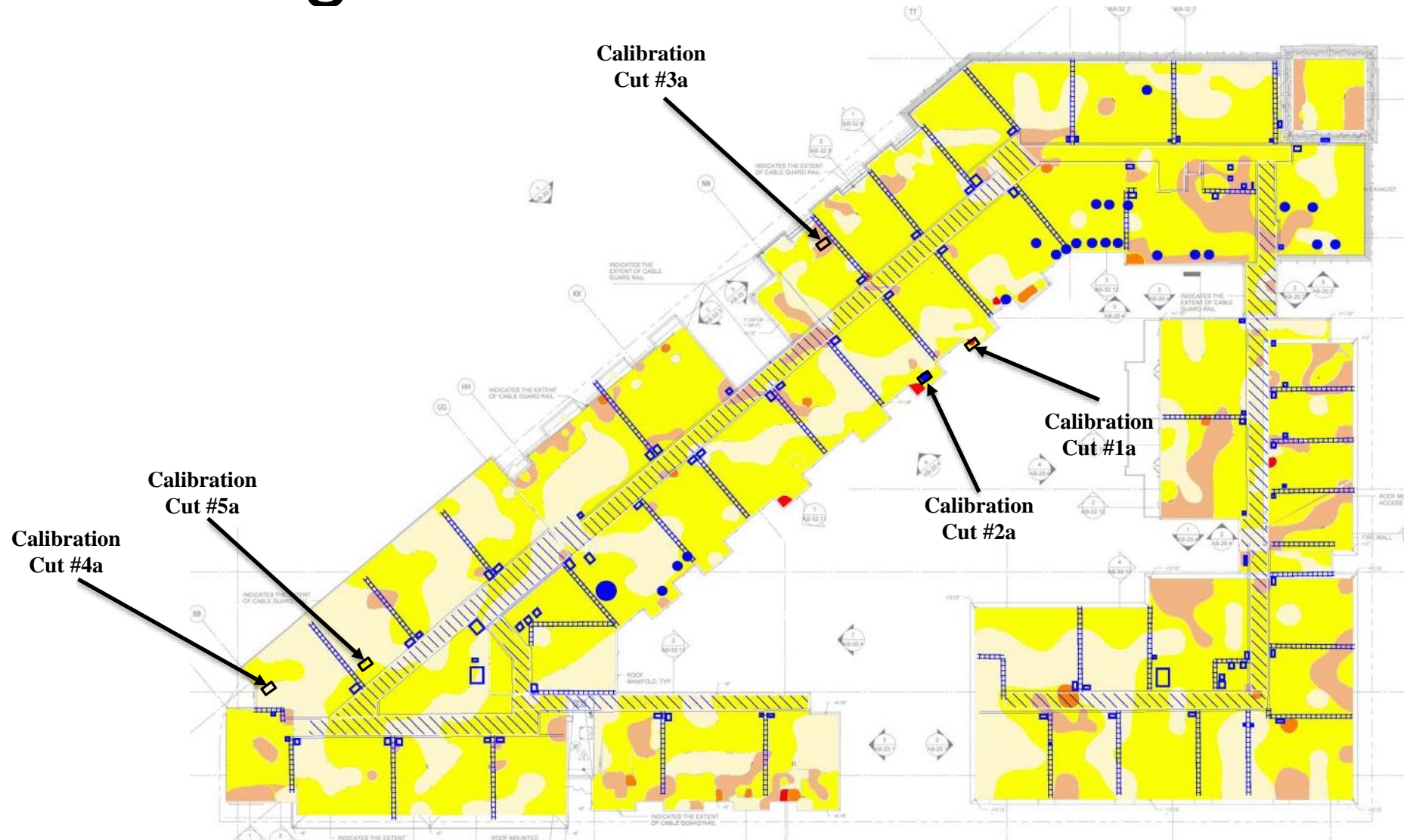
Non-Destructive Nuclear Gauge Survey Results



Calibration Roof Cuts



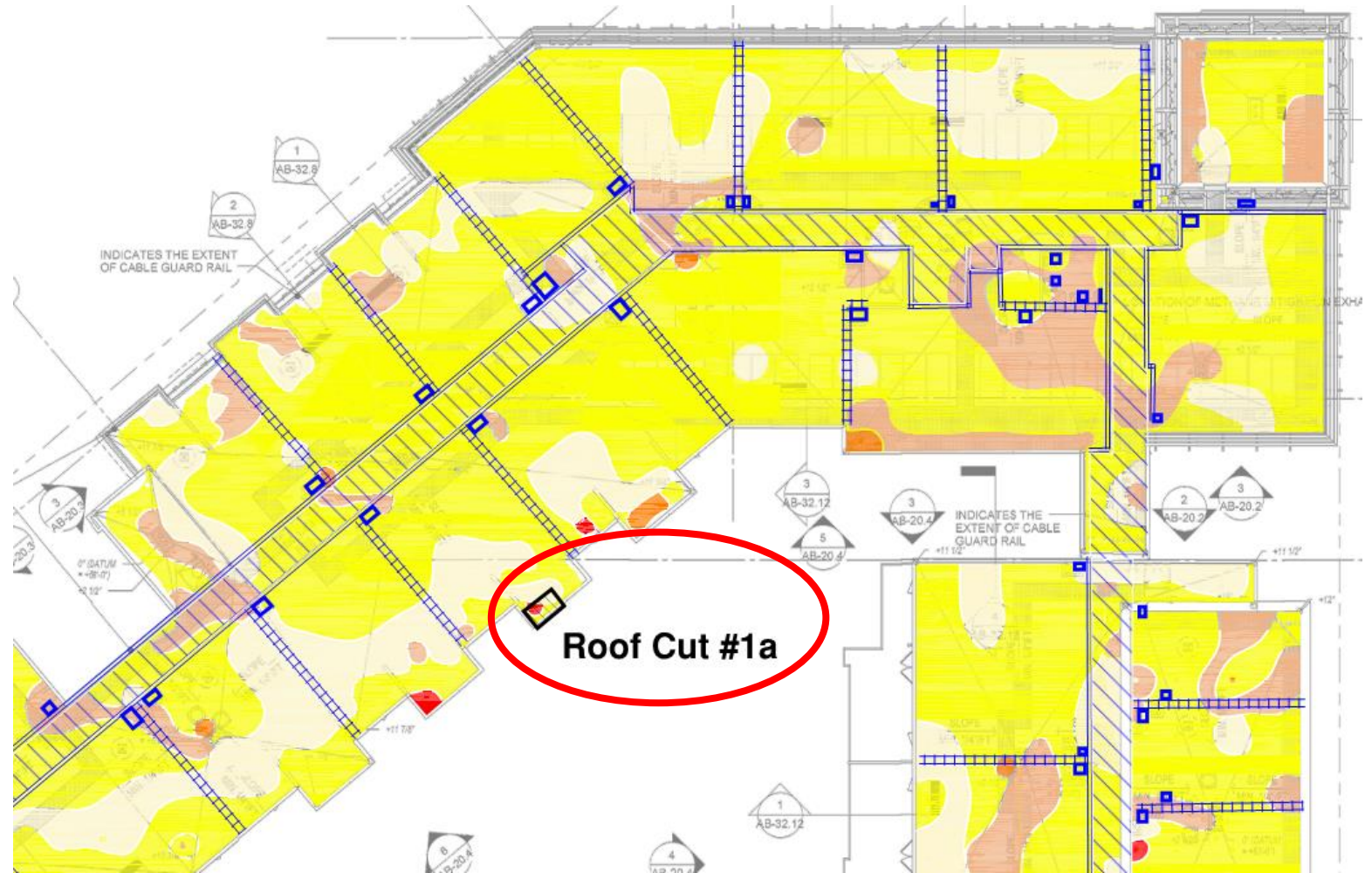
Nuclear Gauge Calibration Test Cut Locations



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)



Nail Pull Thru Testing:
5/8" Moderate Damage
Avg. 495 lb.

Underside of Cover Board



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

Nail Pull Thru Testing:
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

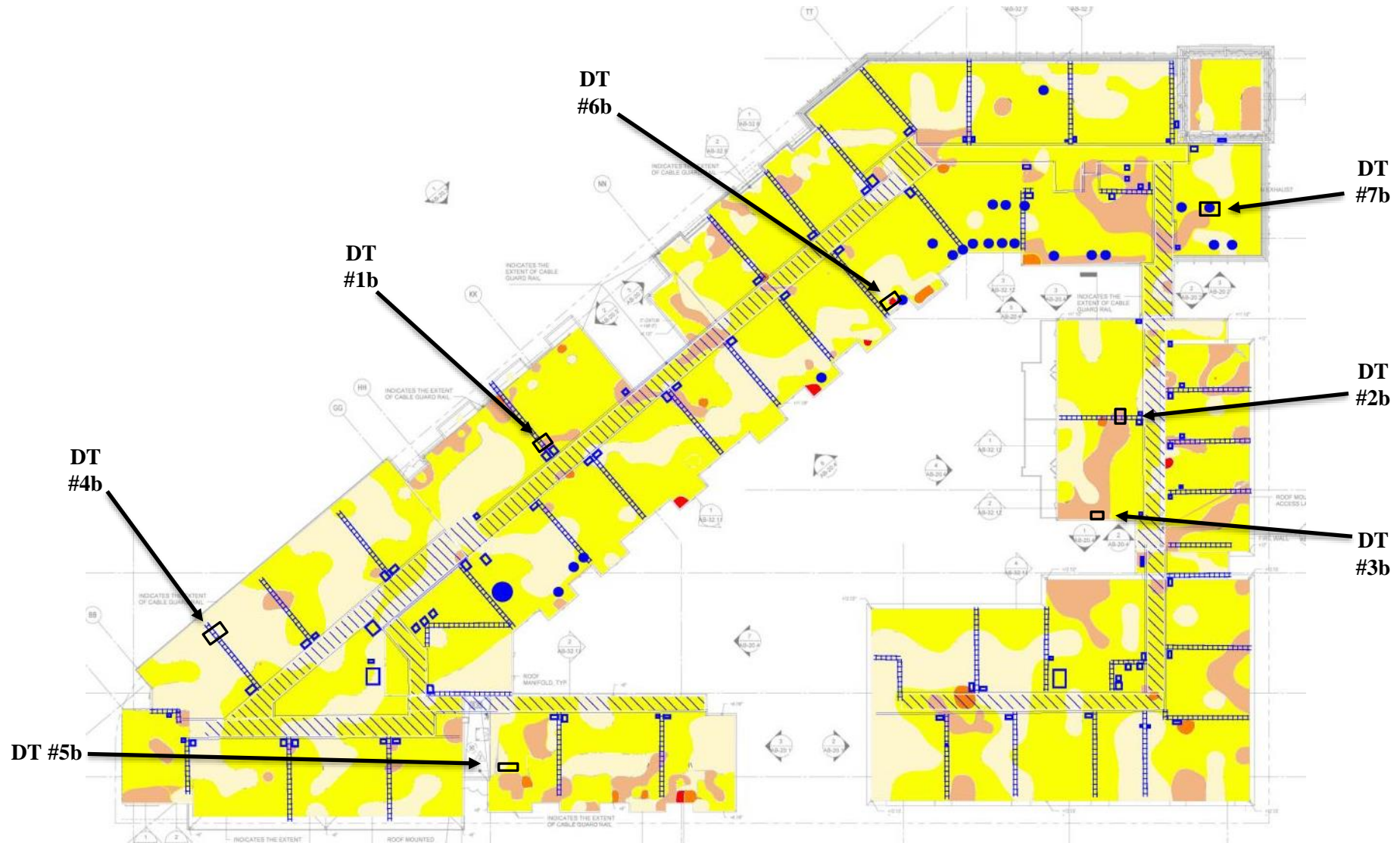




Other Destructive Testing Cuts



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)

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



Damage on Backside of Plywood Cricket

Destructive Test
Cut #3b



Water and Staining within Cricket Cavity

Destructive
Test Cut #3b

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



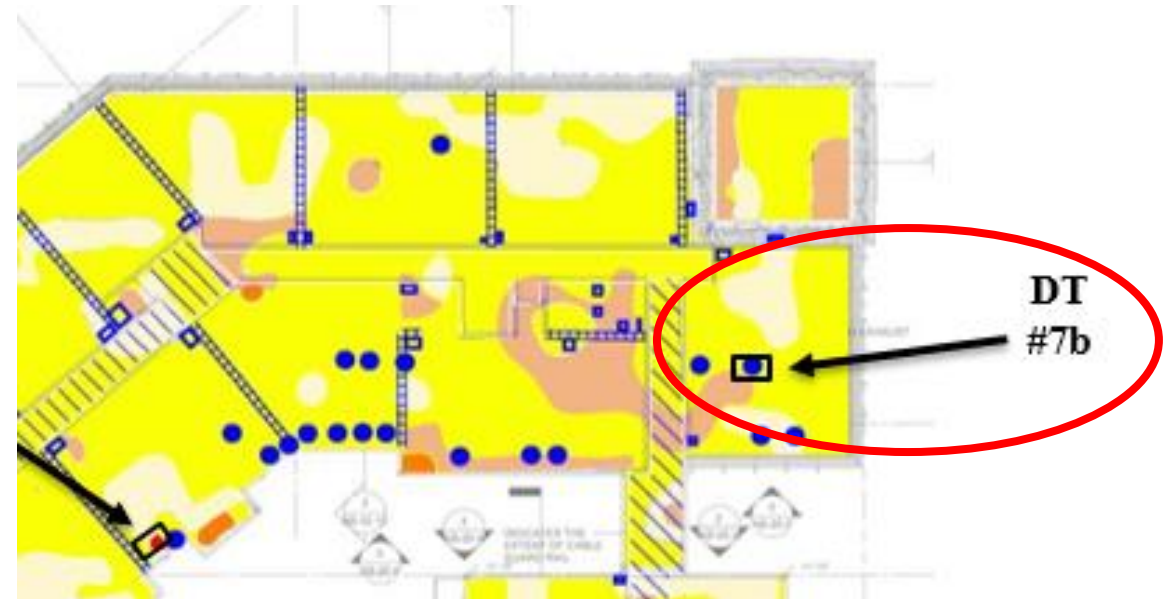
Corroding Fastener in Cricket Sheathing

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.

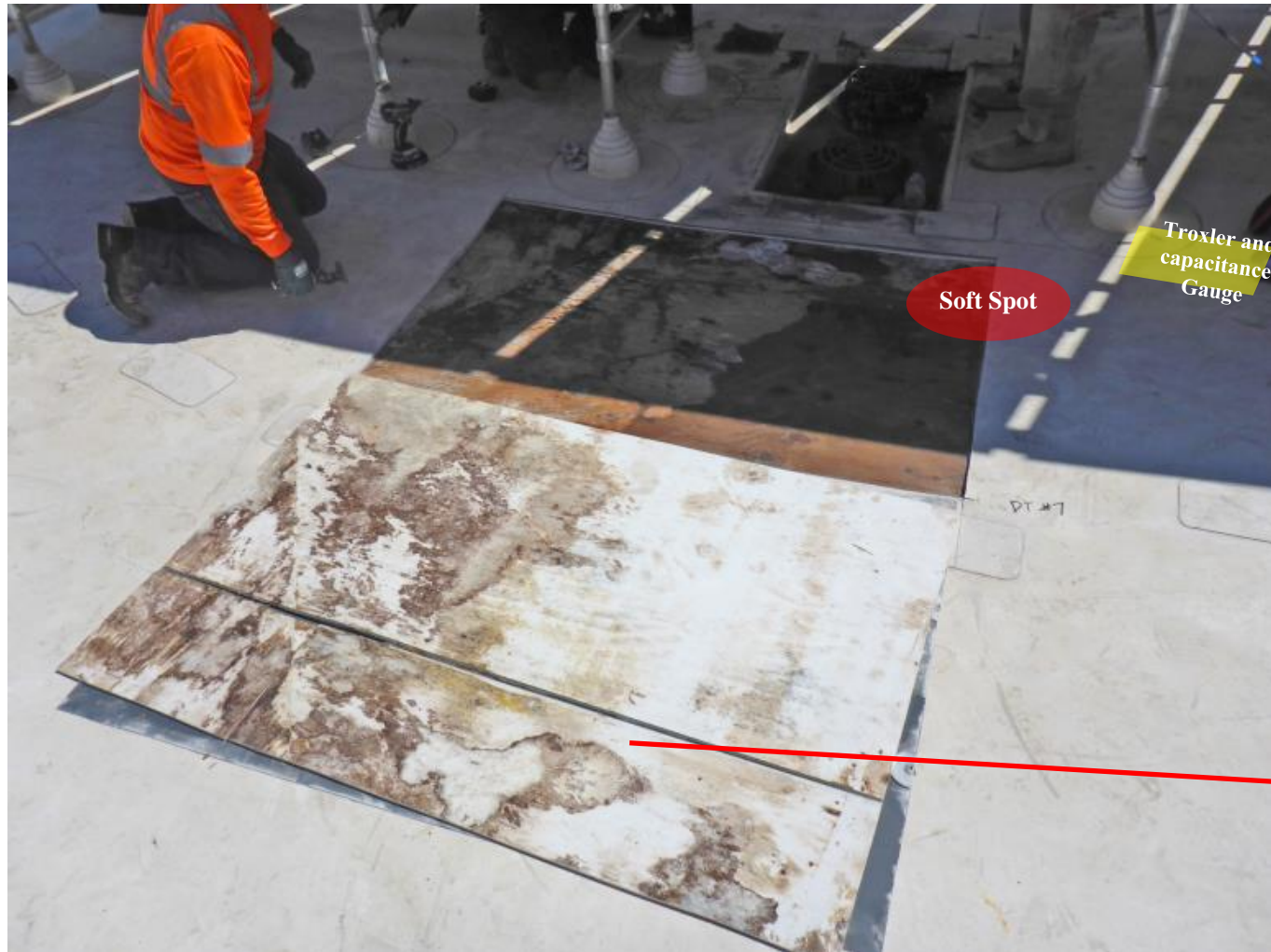


Moisture Scan Results

Destructive Test Cut #7b (Soft Spot)



Destructive Testing Cut # 7b, Severe Damage



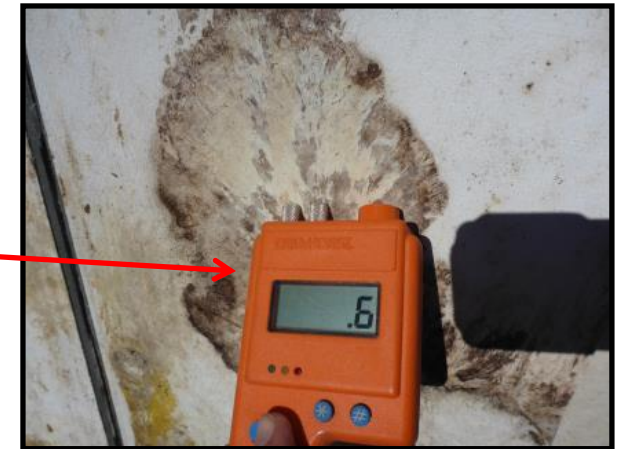
Nail Pull Thru Testing:

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



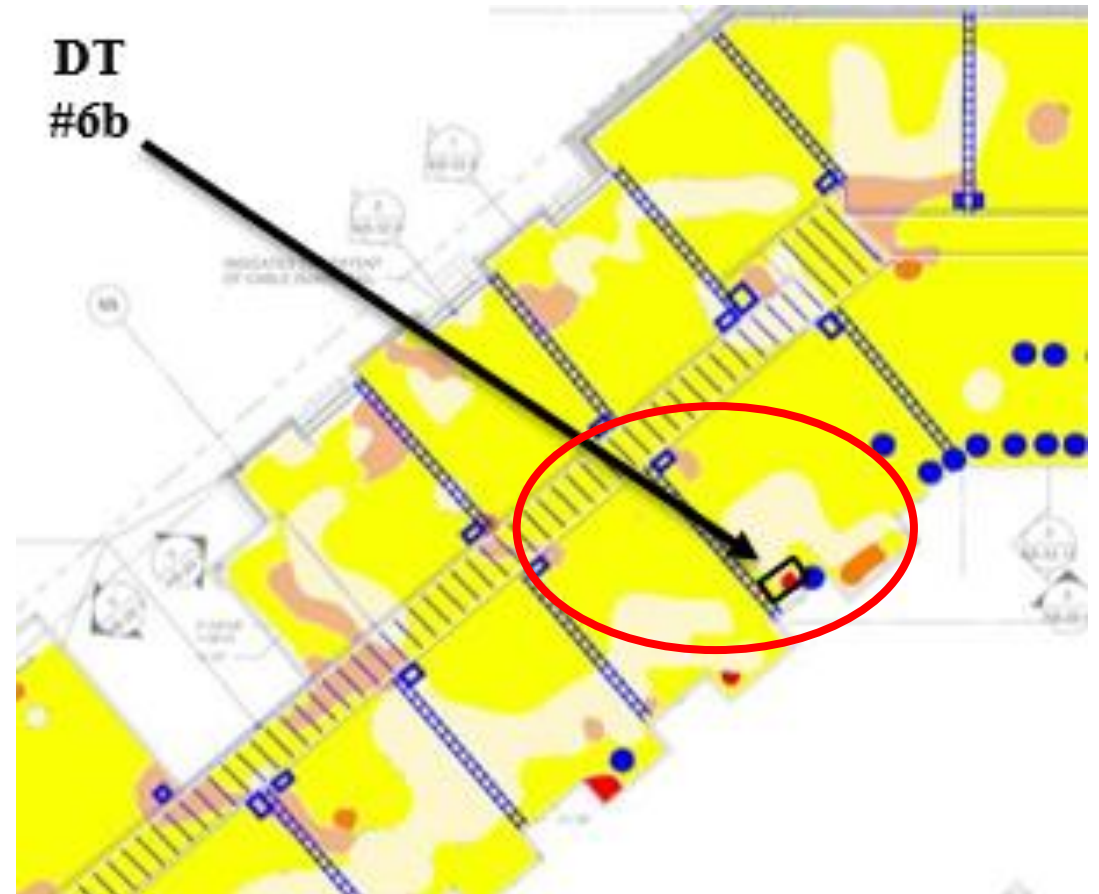
Corroding Drain Bowl

Destructive Test Cut #7b



Destructive Test Cut #6b

- Test Cut Location: 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



A photograph of a mechanical testing device used for plywood nail pull-through testing. The device is mounted on a wooden surface. It features a vertical threaded rod with a black handle at the top. A digital force gauge is attached to the side of the device. A small piece of white tape with the handwritten number 'P2' is on the wooden surface to the right of the device. The background shows a grey metal frame.

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



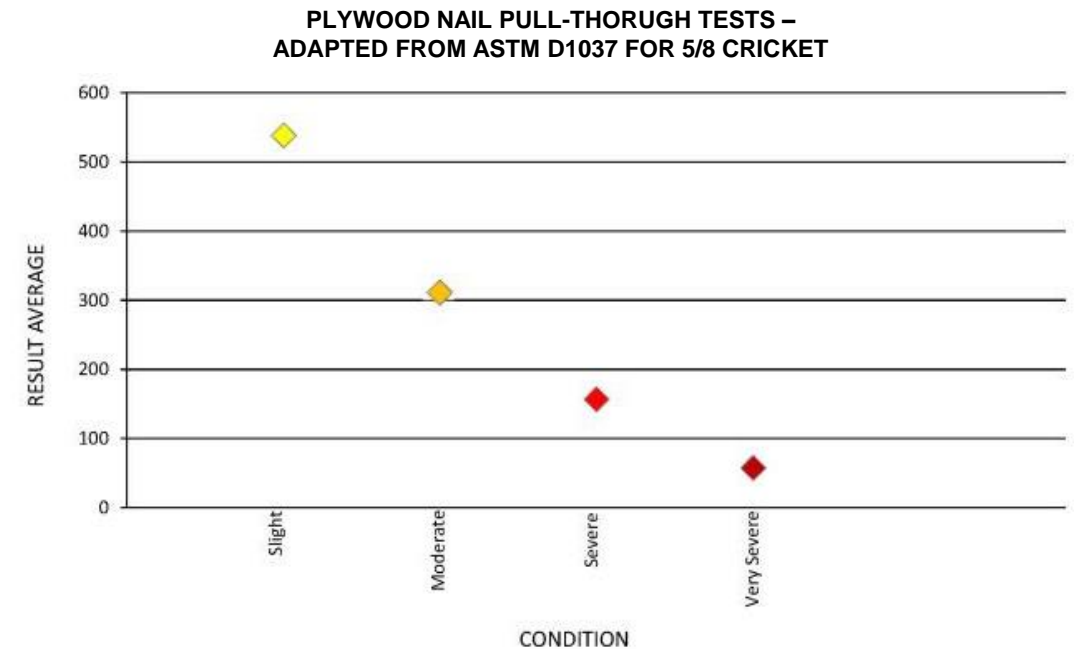
Photos of Pull Testing



COM-TEN Digital Pull Tester in place during testing

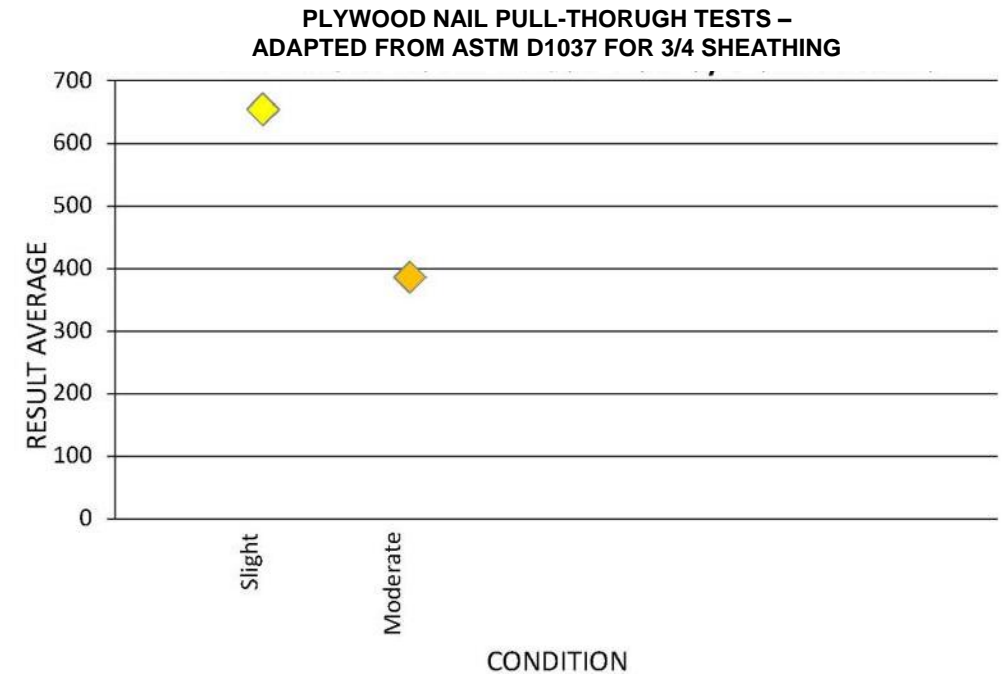
Nail Pull Through - 5/8" Cricket Sheathing

| 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 | |
| P25 | Destructive Test Cut #7 | Very Severe | 16.4 | 58.2 |
| 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 | |





Vapor Retarder Membrane Installation



Manufacturer's Instructions for Tears and Holes

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.

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.

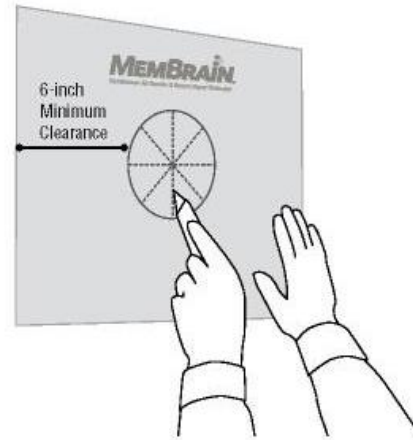


Figure 10: Patch preparation.

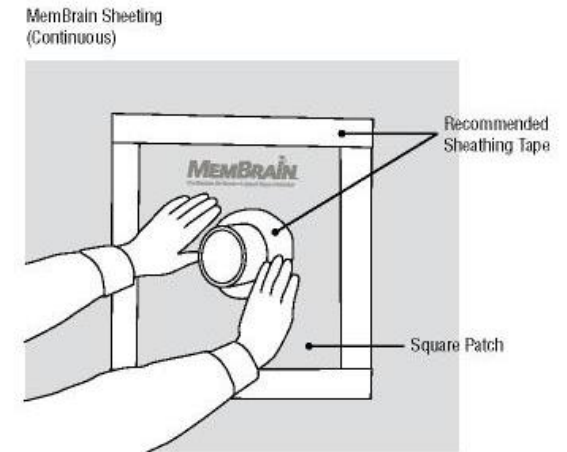


Figure 11: Patch attachment.



Vapor Retarder Installation Instructions at Walls

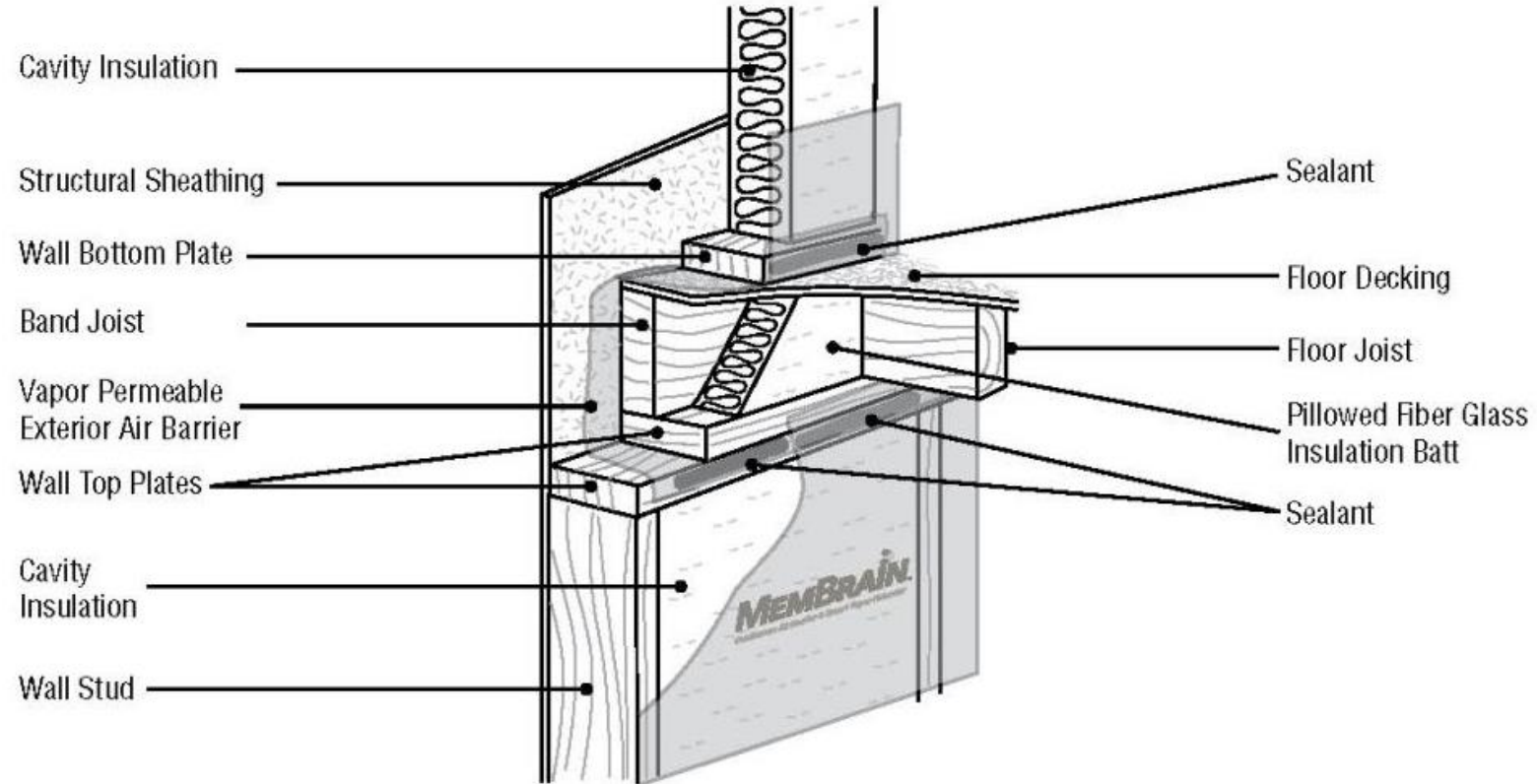


Figure 17: Detail B— MemBrain Air Barrier System interior floor intersection details.



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

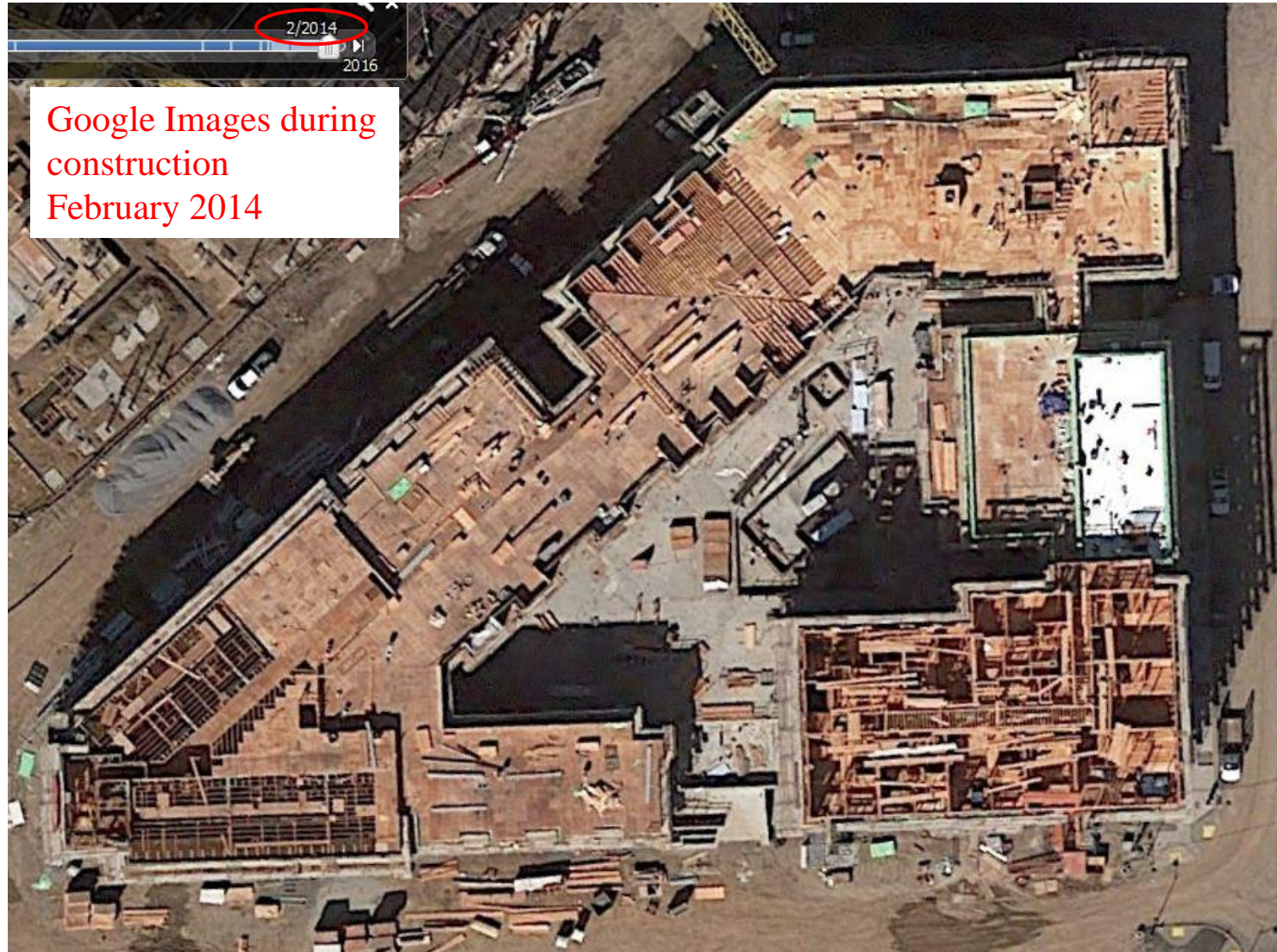


A close-up photograph showing significant weather damage to wood. On the left, a vertical wooden plank with a clear grain is visible. To its right, the wood surface is severely deteriorated, showing a rough, splintered, and discolored texture. The background is dark and indistinct.

Damage from Weather Exposure



Weather Exposure



Google Images during
construction
February 2014



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

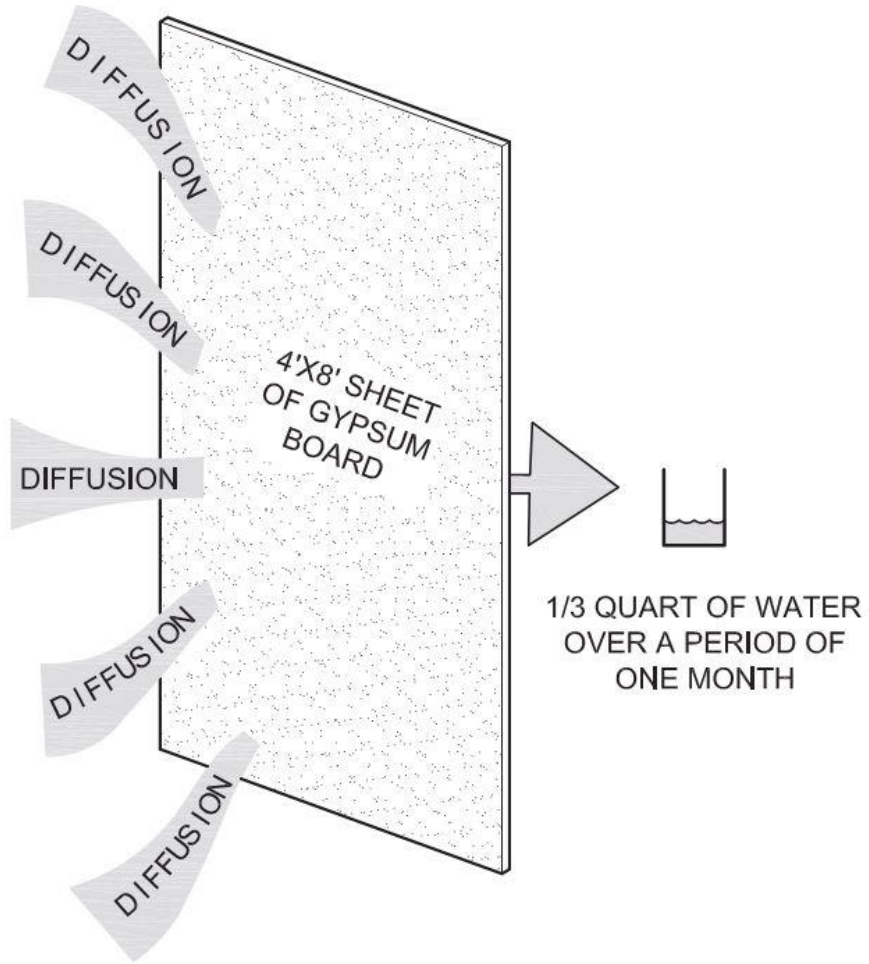


What is a Vapor Retarder?

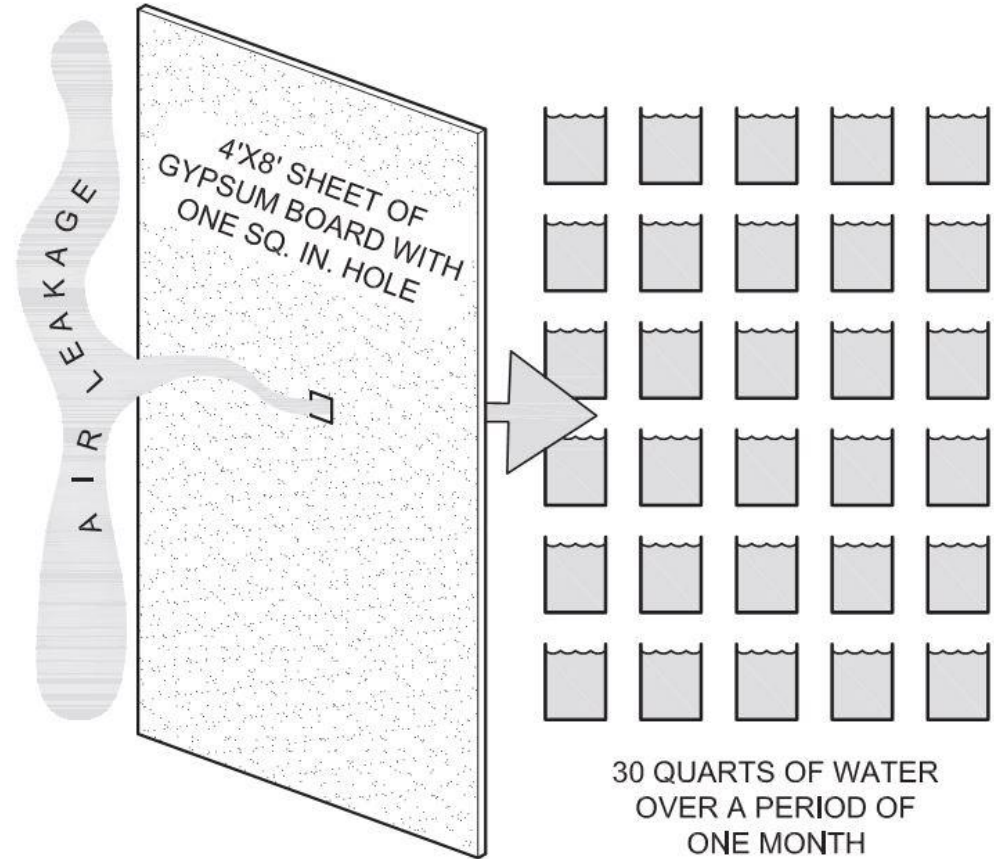
- If it's less than or equal to 10 perms, it's a vapor retarder.
 - Plywood
 - Asphalt Saturated Sheathing Paper
 - Polyethylene
 - PVC Roof Membrane
- Permeance vs. Permeability
 - Permeance is the vapor transmission rate through a material of a given thickness; stated in perms.
 - Permeability is a material property and is the arithmetic product of permeance and thickness; stated in perm-inches.



Vapor Diffusion vs. Air Leakage



VAPOR DIFFUSION



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 perm | 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].

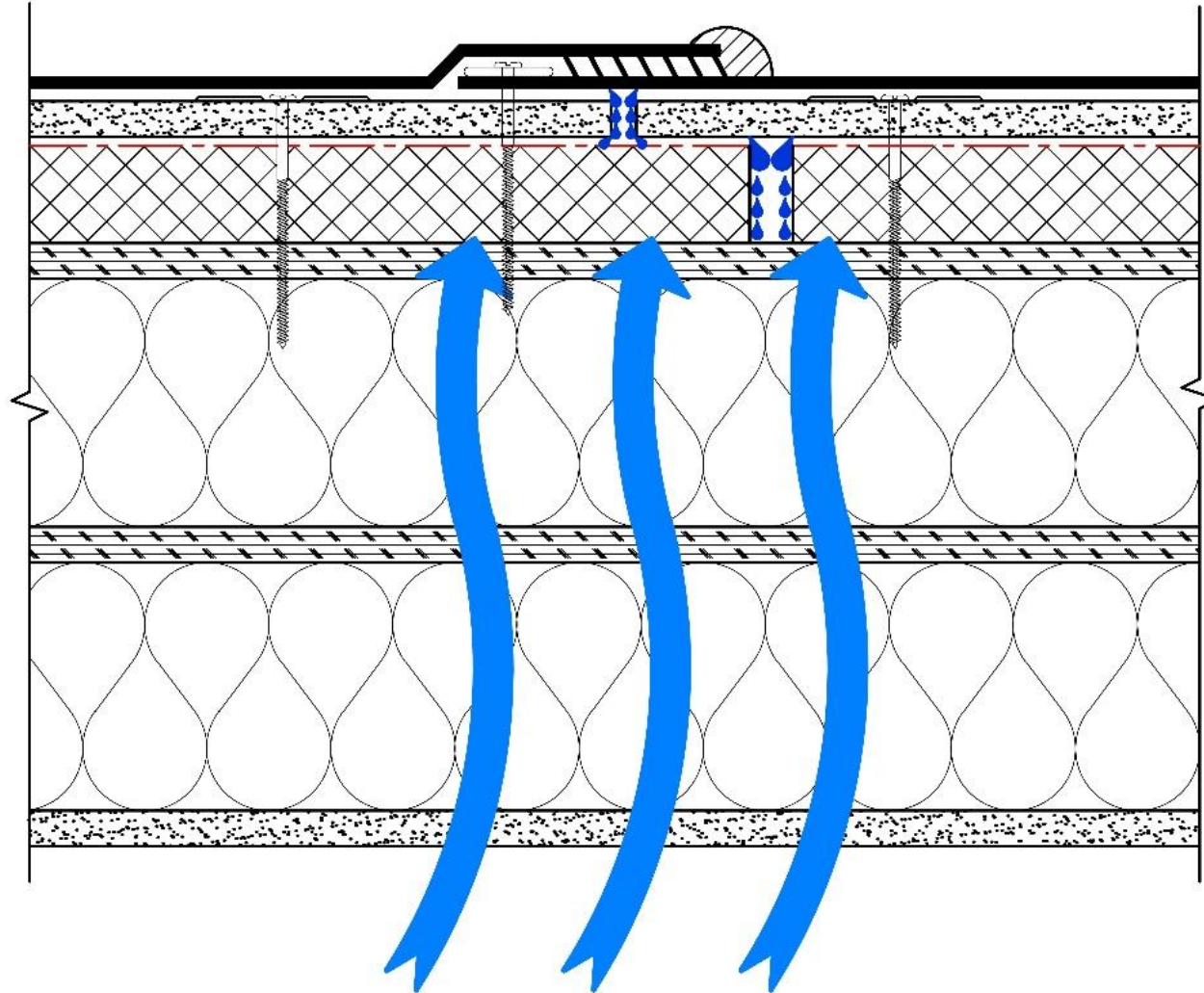
X1.1.5 *Procedure D*—Water Method at 90°F [32.2°C].

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

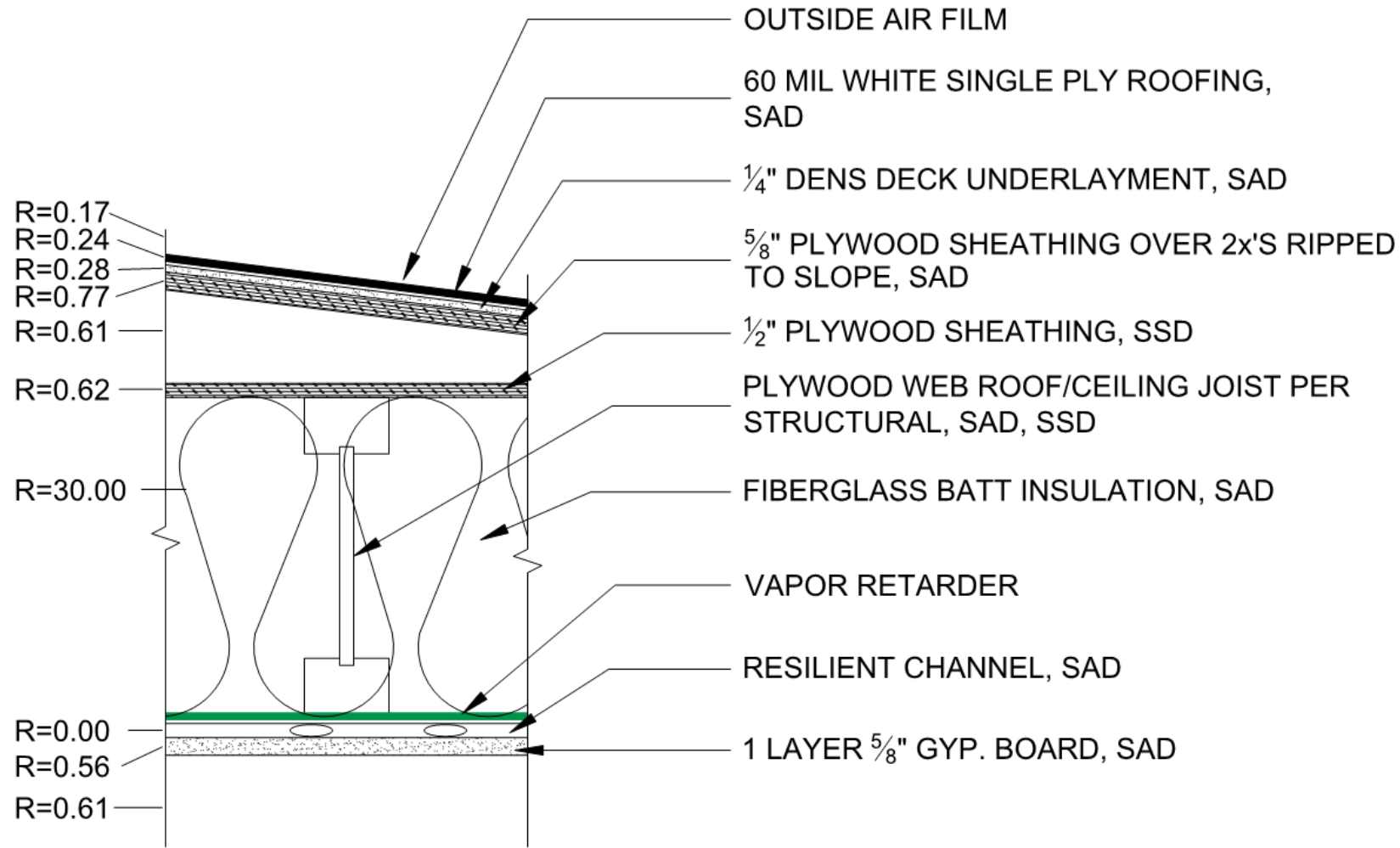
X1.2 Unless otherwise prescribed by regulation, specification, ASTM standard, or other governing document, select test conditions similar to those to which the material will be exposed to actual use.



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: $T_{P1} = T_i - \left[\left(\frac{\Sigma R_1}{\Sigma R} \right) (T_i - T_o) \right]$

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

$$\Sigma R_1 = 0.61 + 0.56 = 1.17$$

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

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

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

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

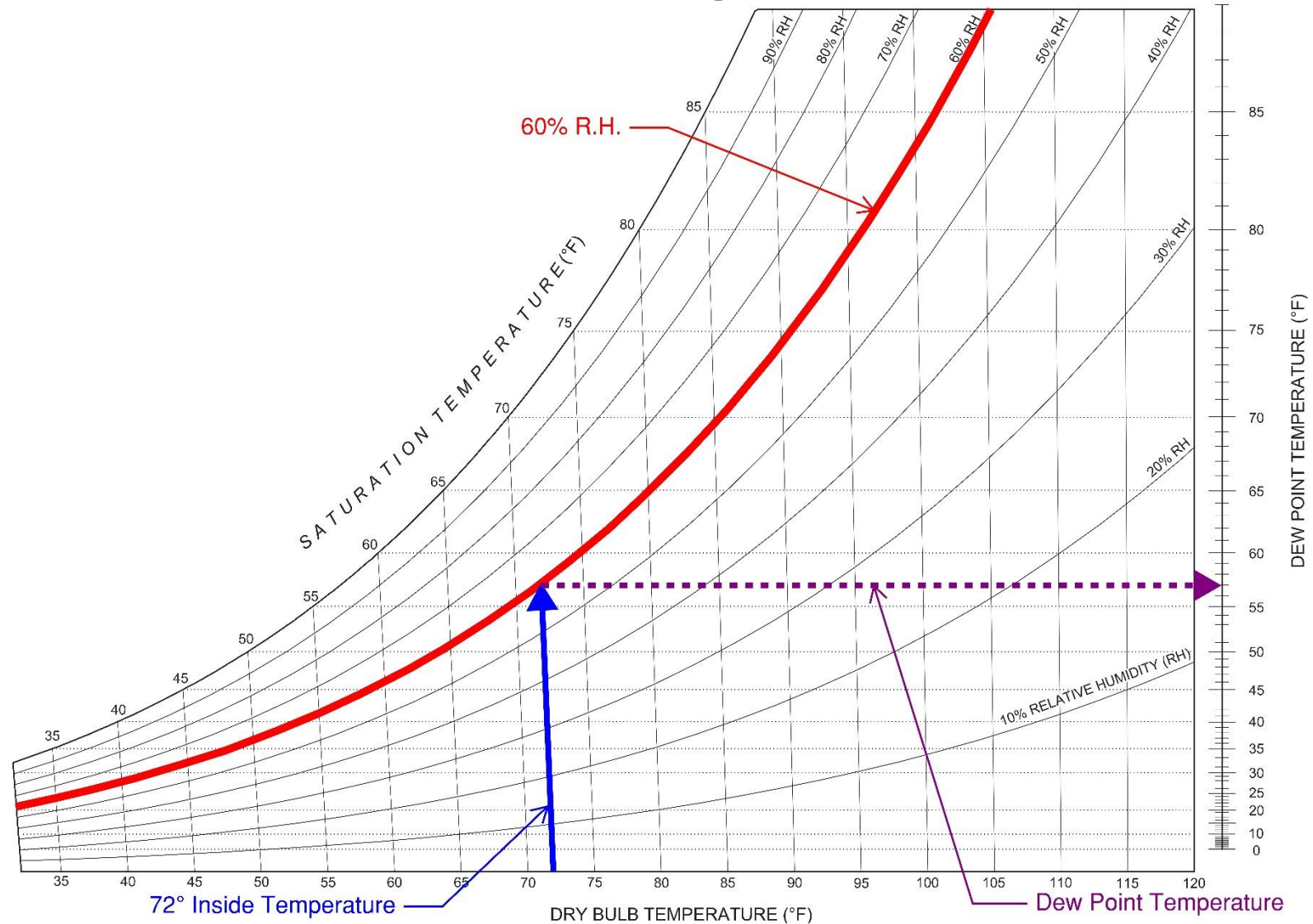
$$T_{P3} = 72^\circ\text{F} - \left[\left(\frac{31.79}{33.86} \right) (72^\circ\text{F} - 34^\circ\text{F}) \right] = 36.32^\circ\text{F}$$

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

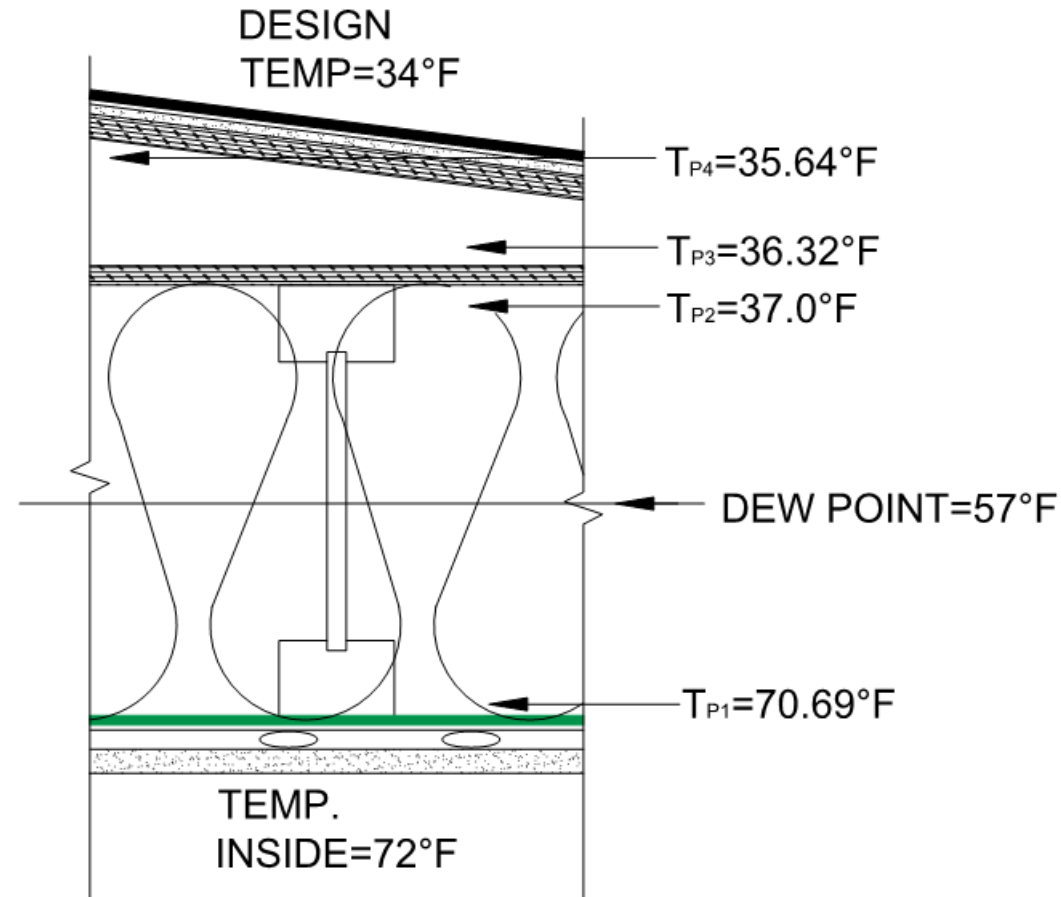
$$T_{P4} = 72^\circ\text{F} - \left[\left(\frac{32.4}{33.86} \right) (72^\circ\text{F} - 34^\circ\text{F}) \right] = 35.6^\circ\text{F}$$



Typical Roof / Ceiling - 1Hr Assembly



Wood Frame Roof – 1-Hr Assembly

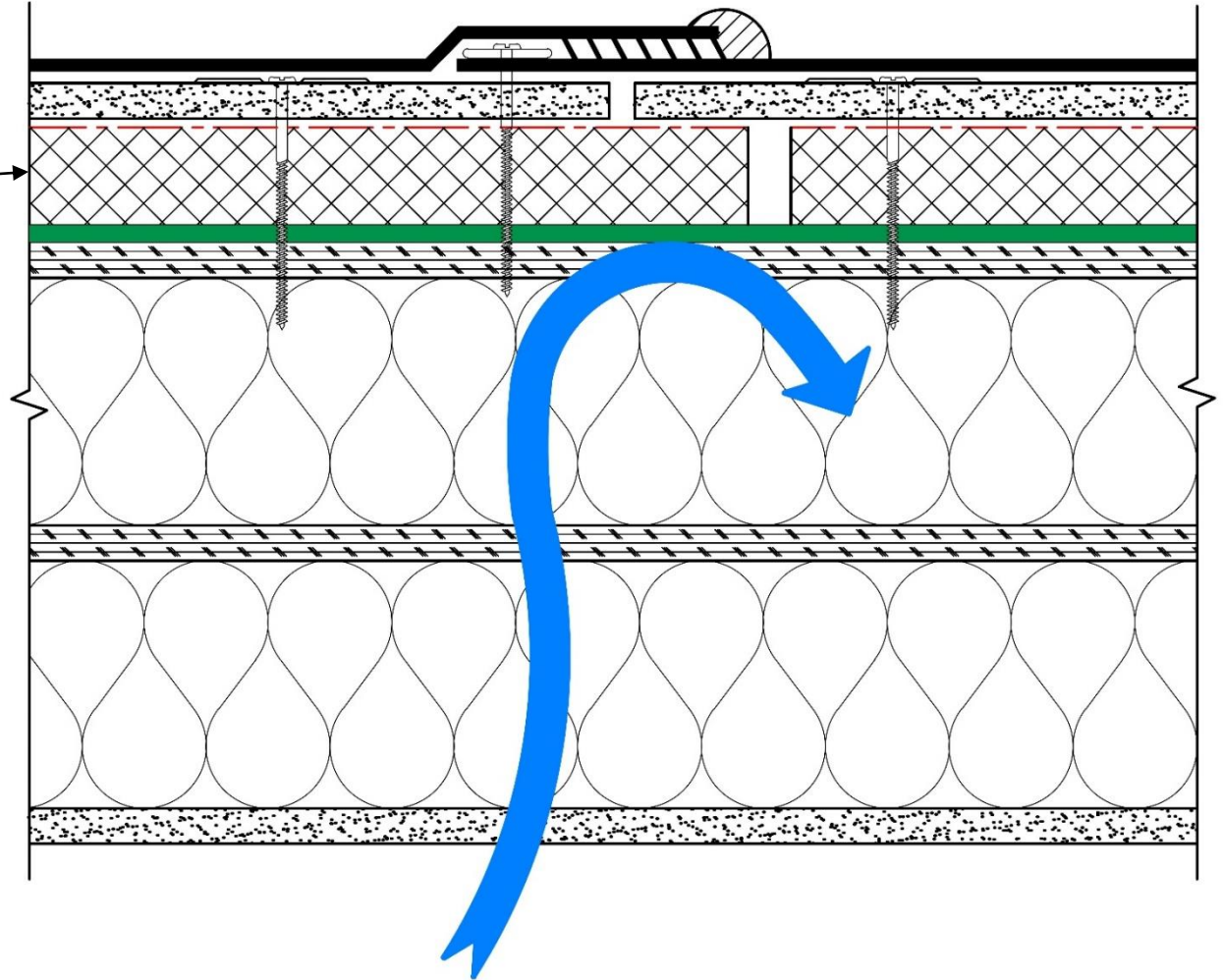


Design Solution – Install a Vapor Retarder

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

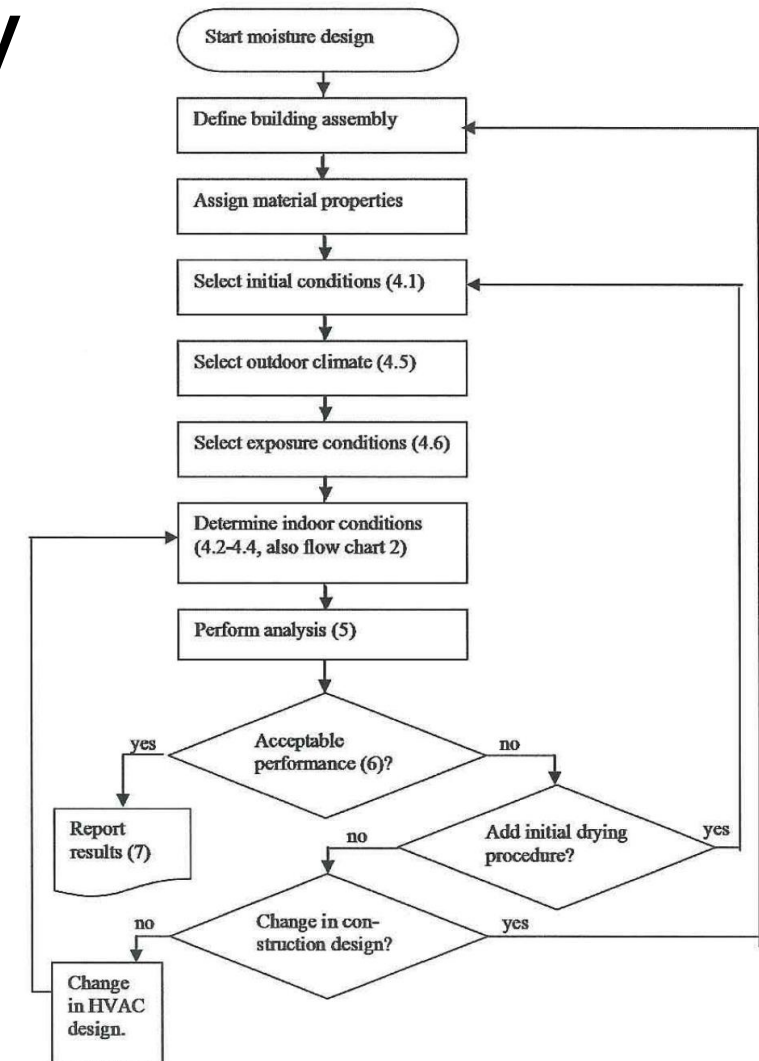
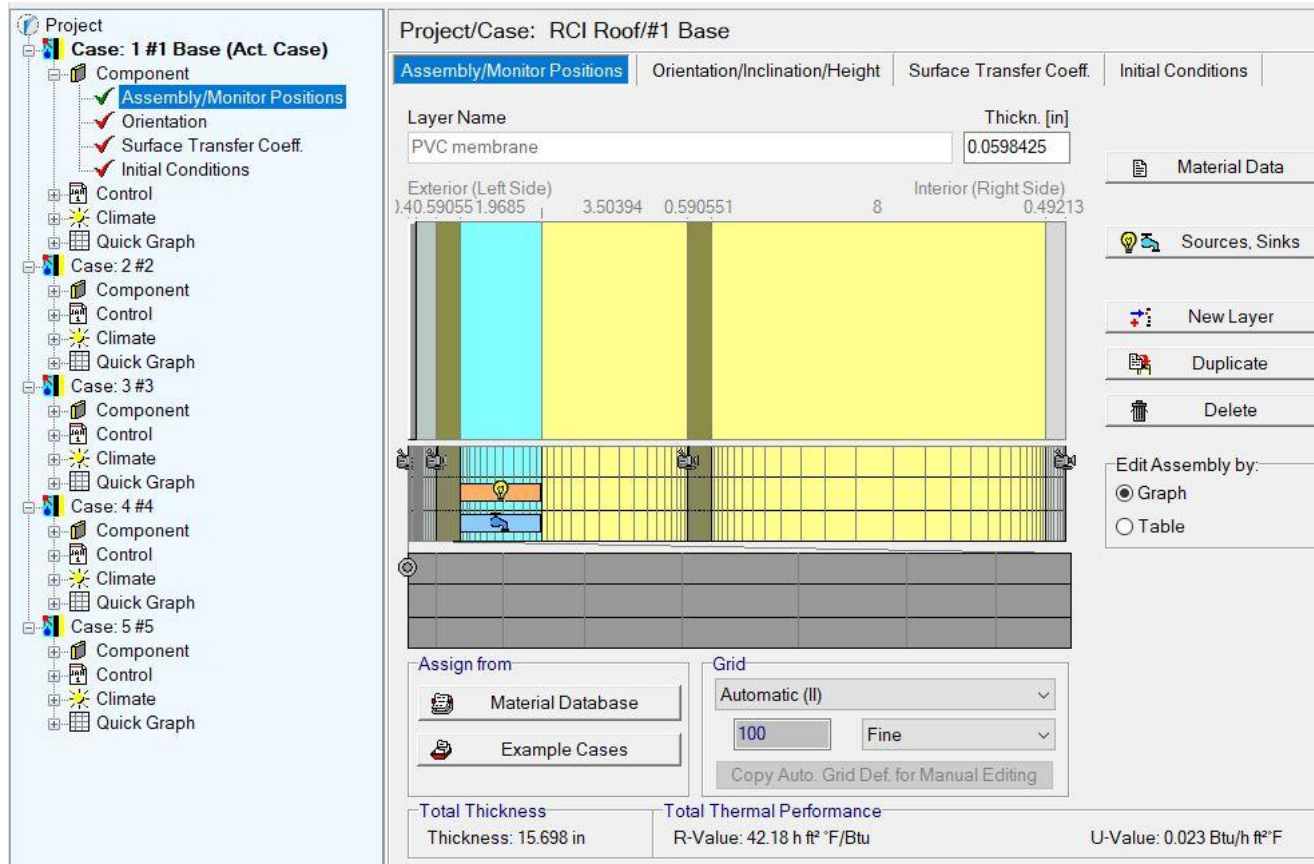


ANSI/ASHRAE Standard 160-2016
(Supersedes ANSI/ASHRAE Standard 160-2009)
Includes ANSI/ASHRAE addenda listed in Annex D

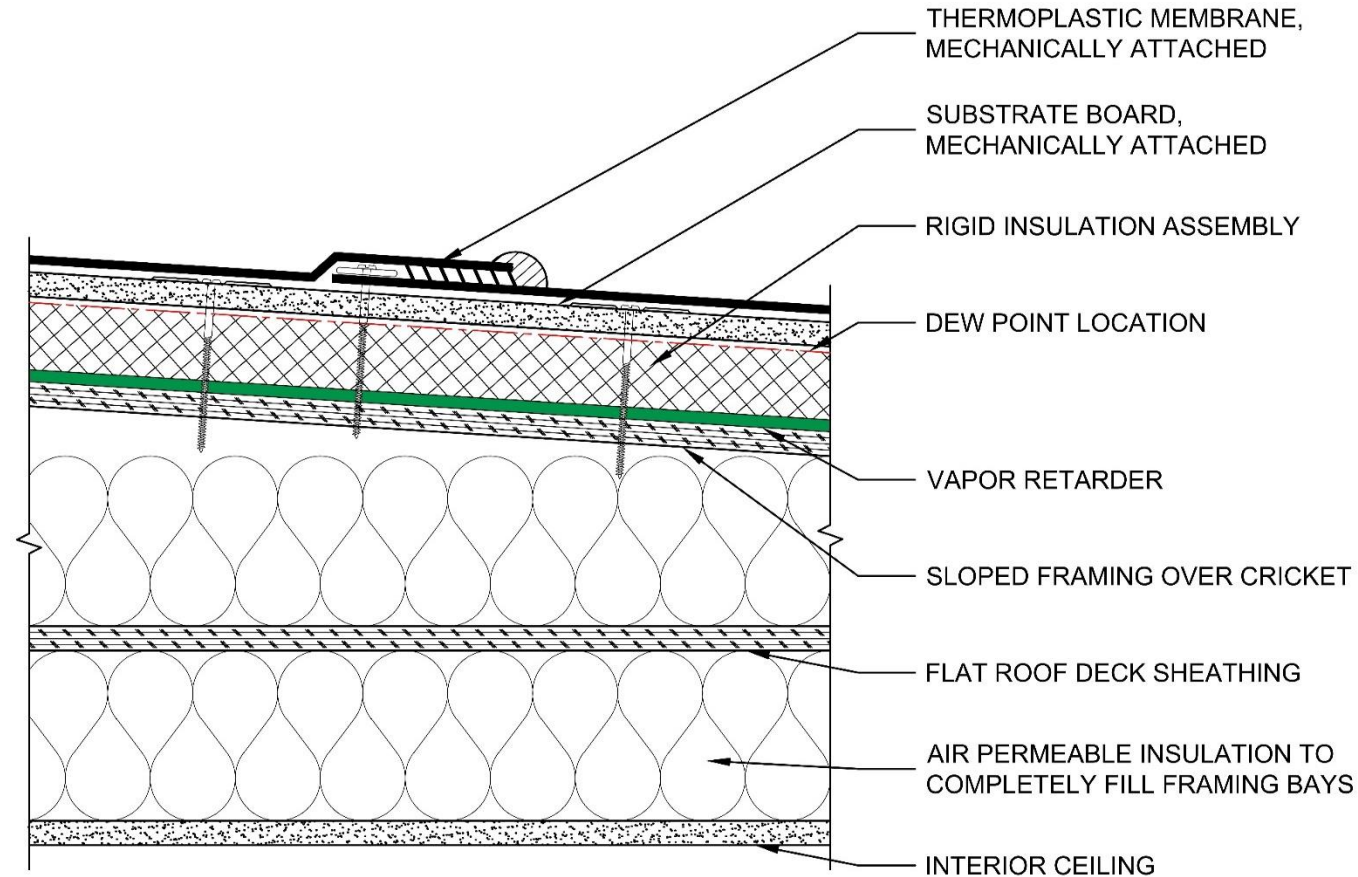
Criteria for Moisture-Control Design Analysis in Buildings



Determining placement of vapor retarder in assembly

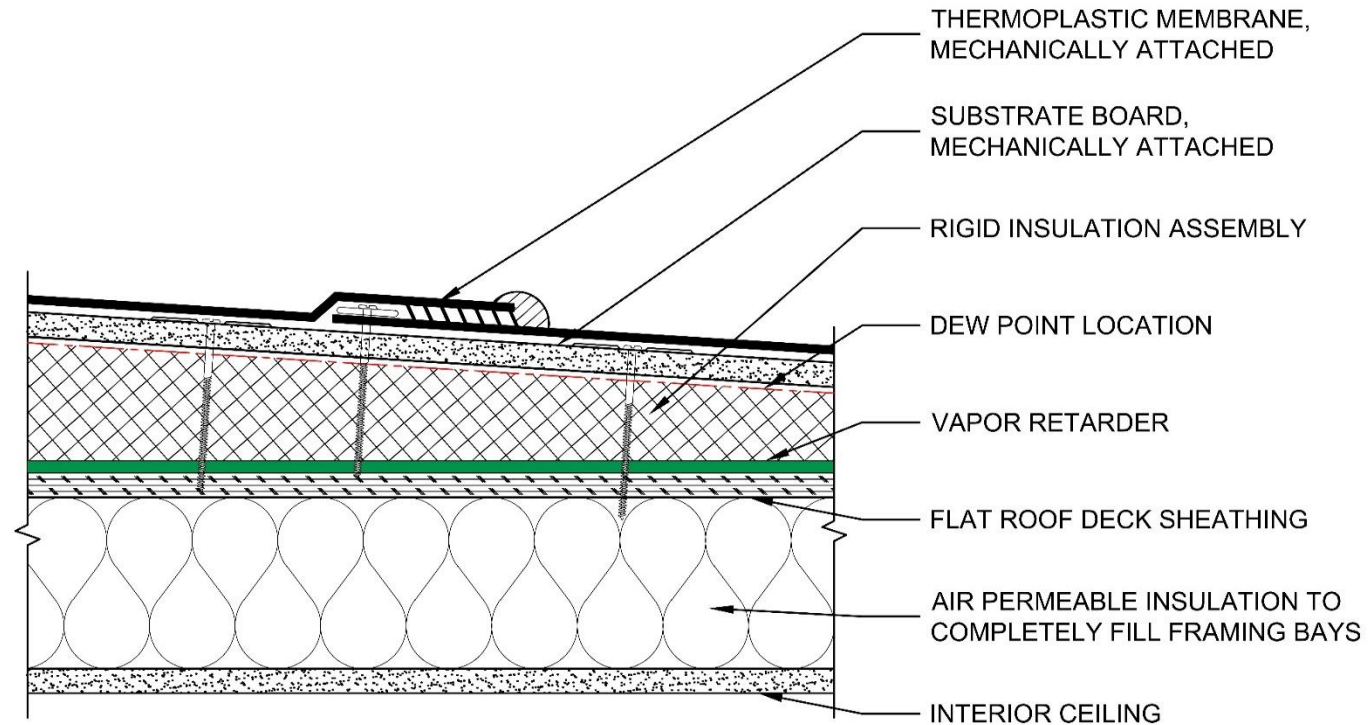


Rigid Insulation with Vapor Barrier



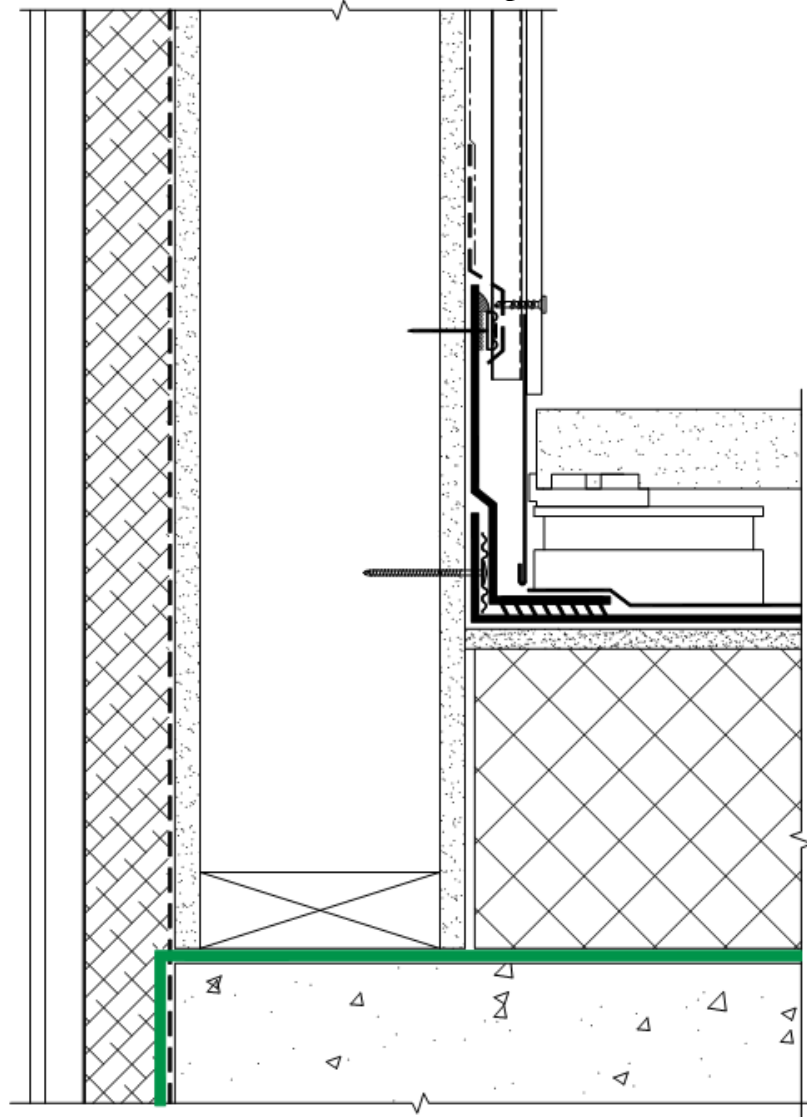
Typical Compact Roof Assembly - Renovation

Rigid Insulation with Vapor Barrier

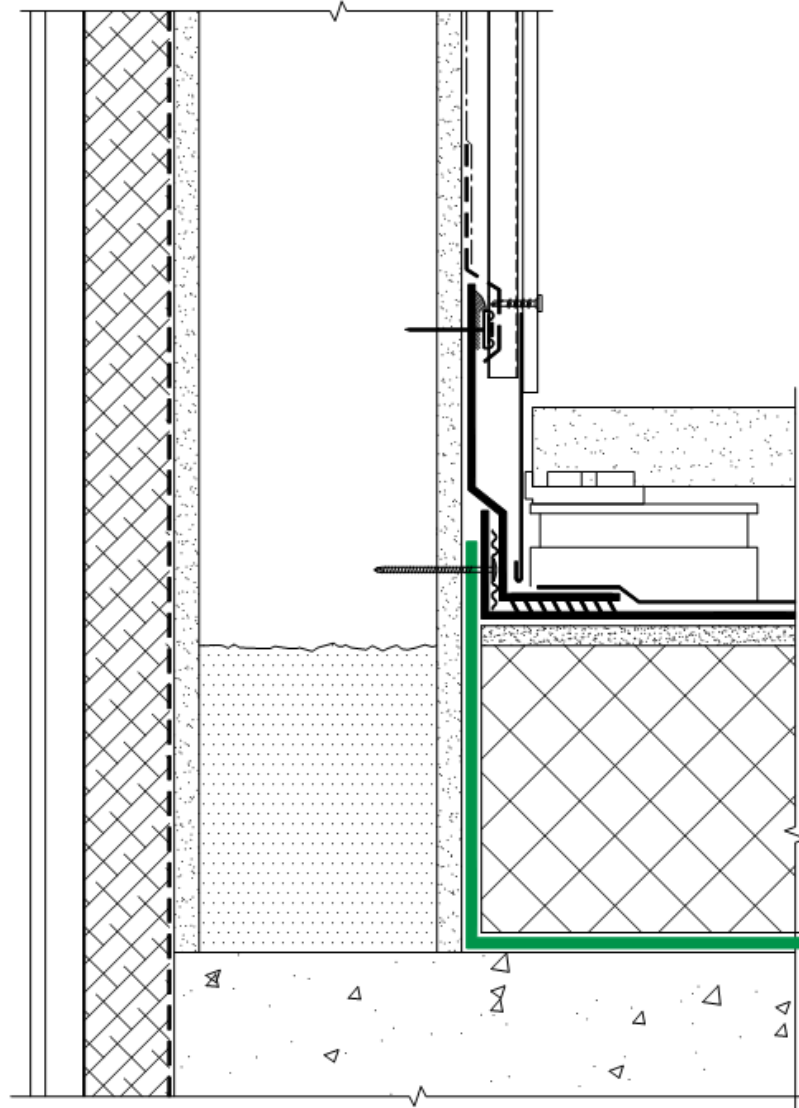


Typical Compact Roof Assembly – New Construction

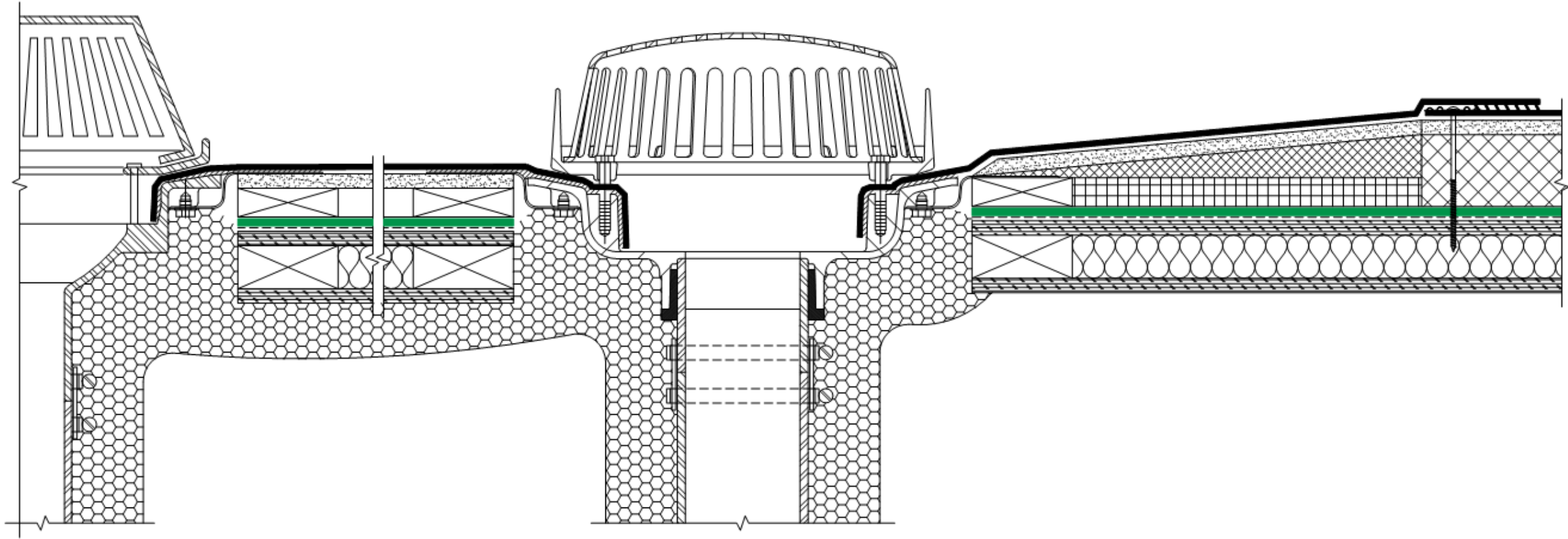
Vapor Retarder Continuity - New Construction



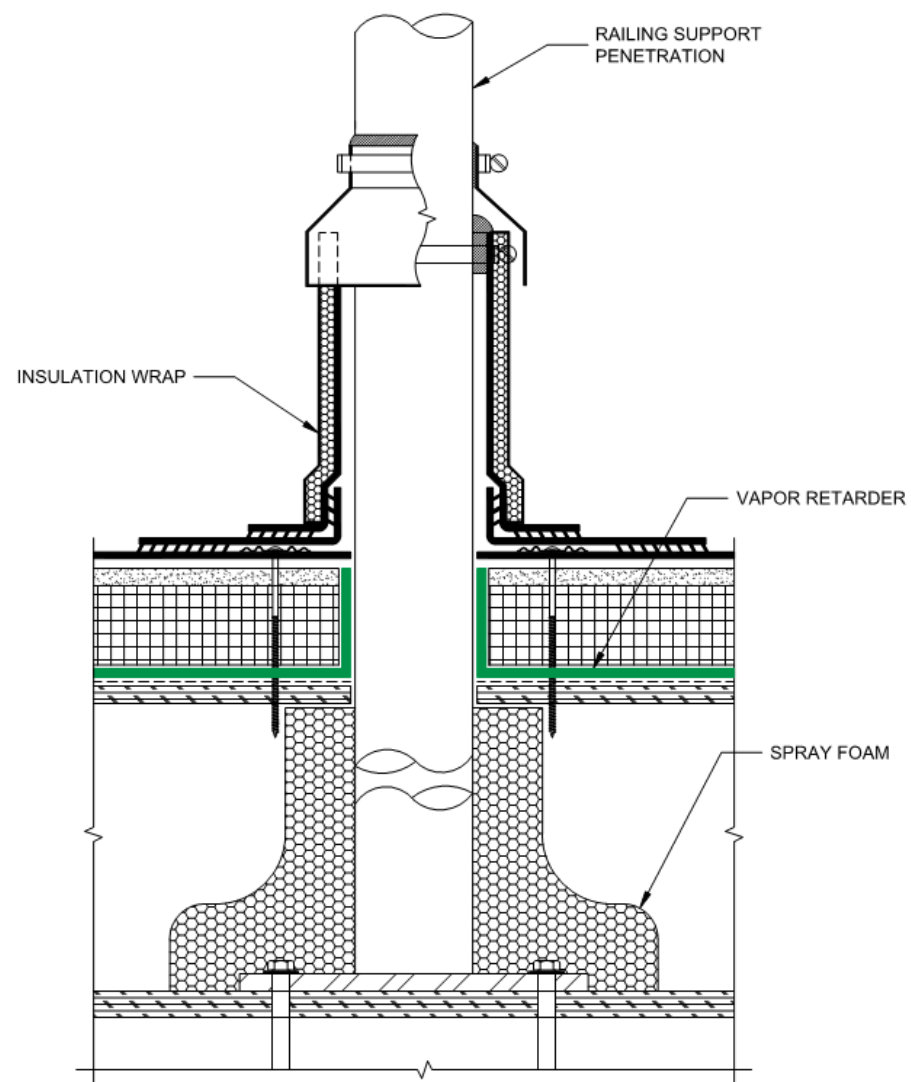
Vapor Retarder Continuity



Vapor Retarder Continuity



Condensation at Penetration



Ventilating Design Options

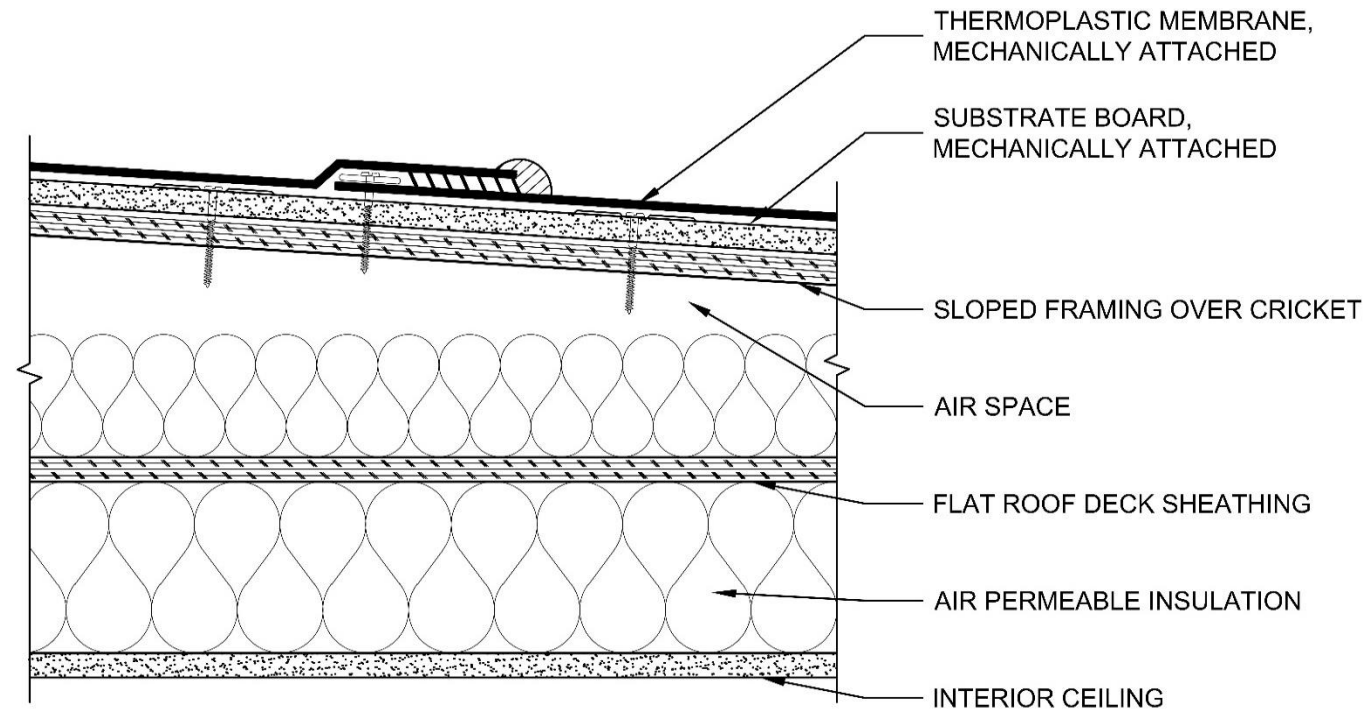


What is Venting?

- 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

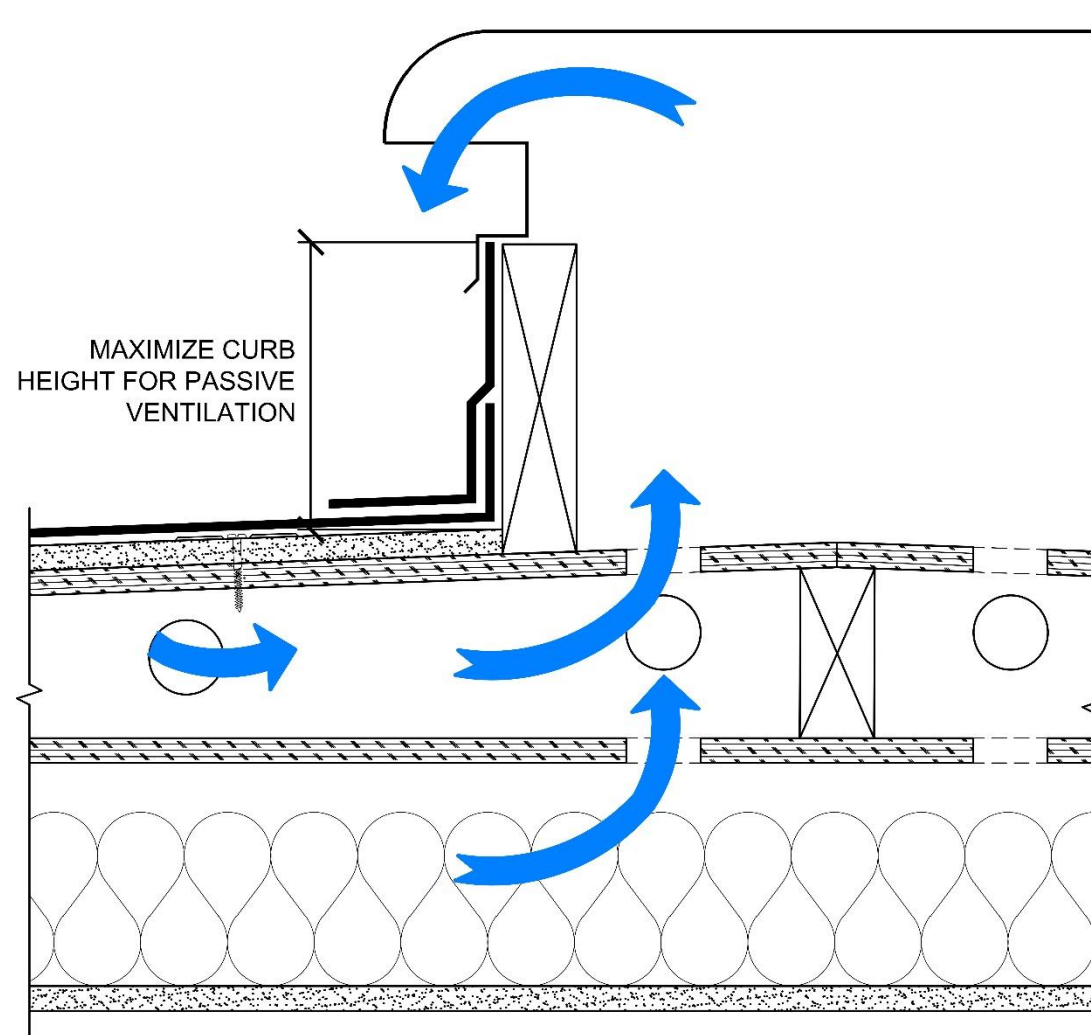
1203.2 Ventilation required. Enclosed attics and enclosed rafter spaces formed where ceilings are applied directly to the underside of roof framing members shall have cross ventilation for each separate space by ventilation openings protected against the entrance of rain and snow. Blocking and bridging 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 $\frac{1}{150}$ 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 $\frac{1}{300}$ provided both of the following conditions are met:

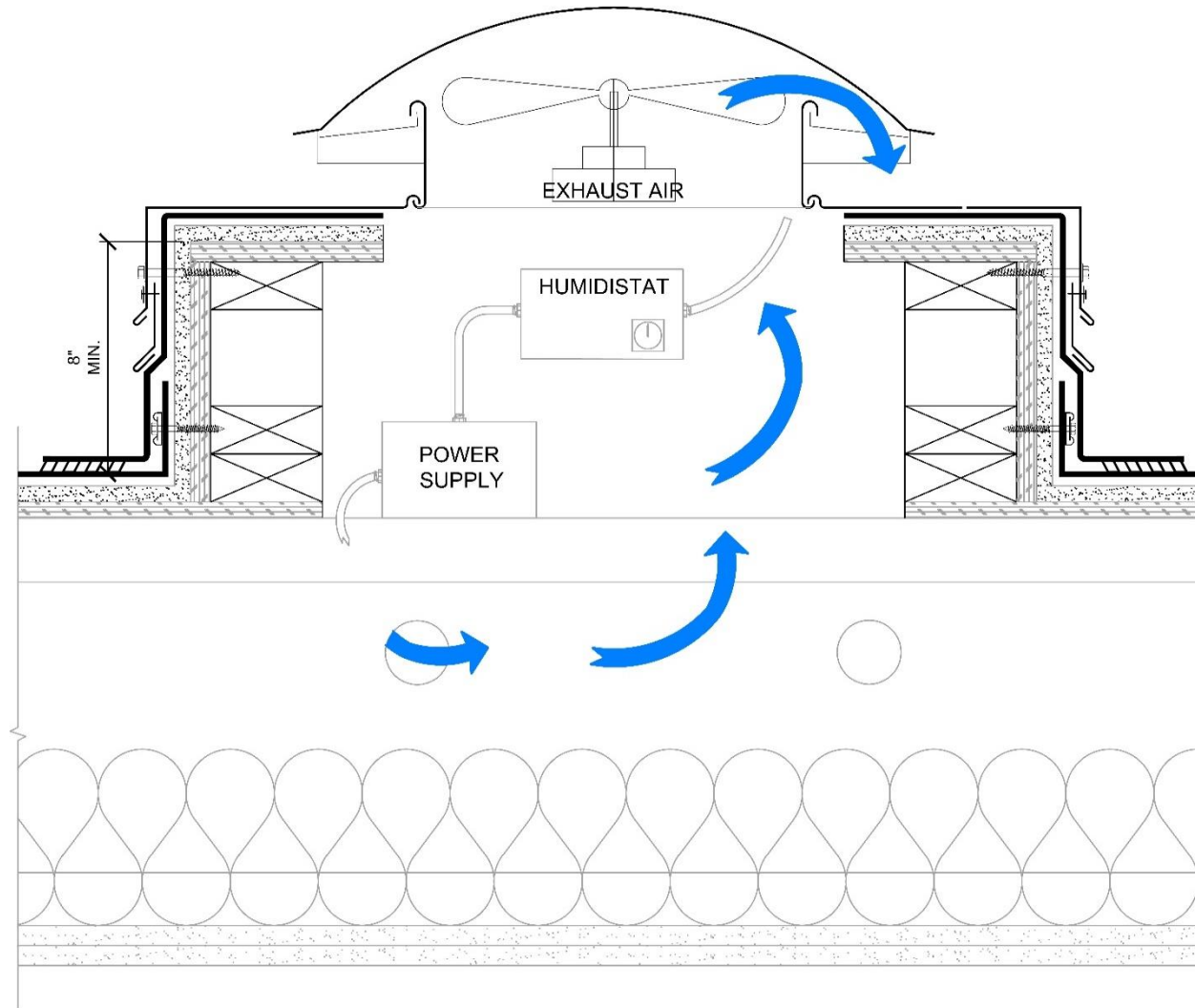
1. In Climate Zones *14 and 16*, a Class I or II vapor retarder is installed on the warm-in-winter side of the ceiling.
2. At least 40 percent and not more than 50 percent of the required venting area is provided by ventilators located in the upper portion of the attic or rafter space. Upper ventilators 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.



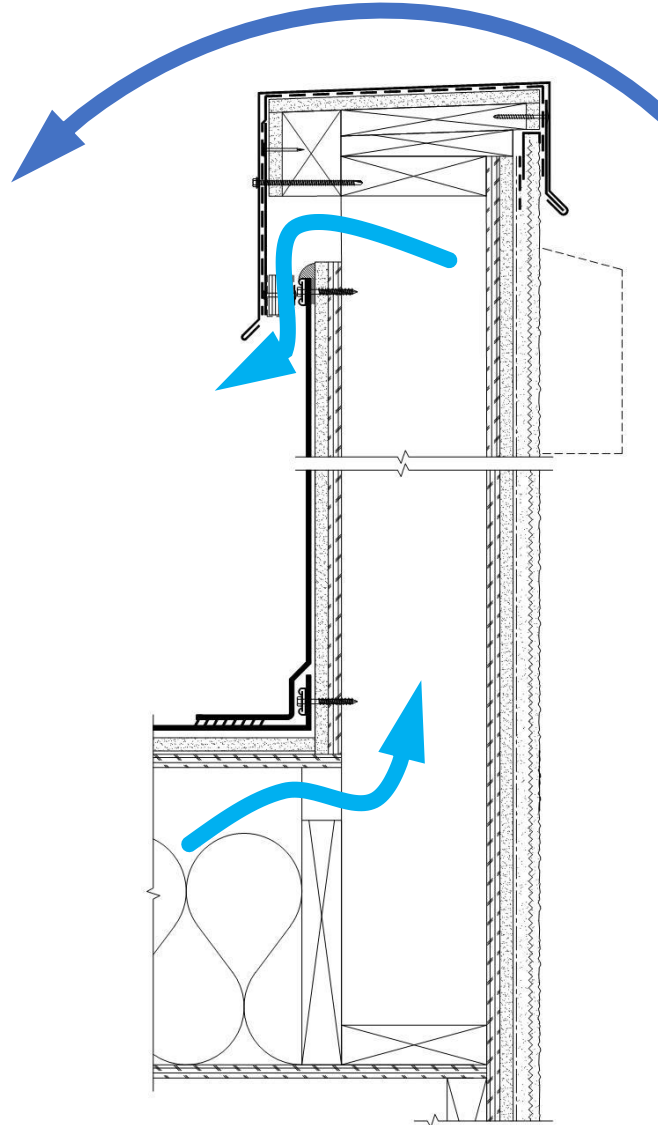
Venting Double Roof Deck With Sloped Framing



Power Ventilation



Venting Double Roof Deck With Sloped Framing

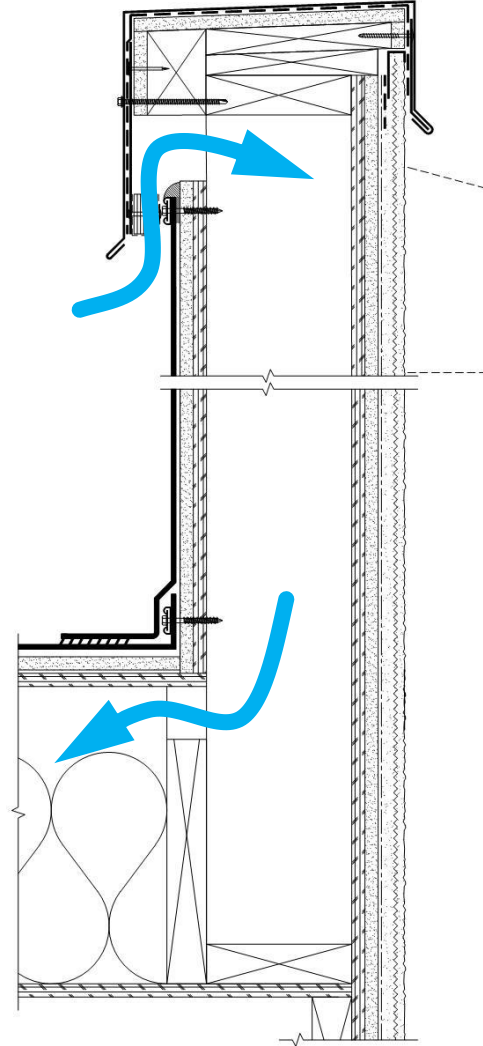


Air flow over the parapet creates negative pressure on the inside of the parapet, pulling air from the assembly.

Passive
Ventilation



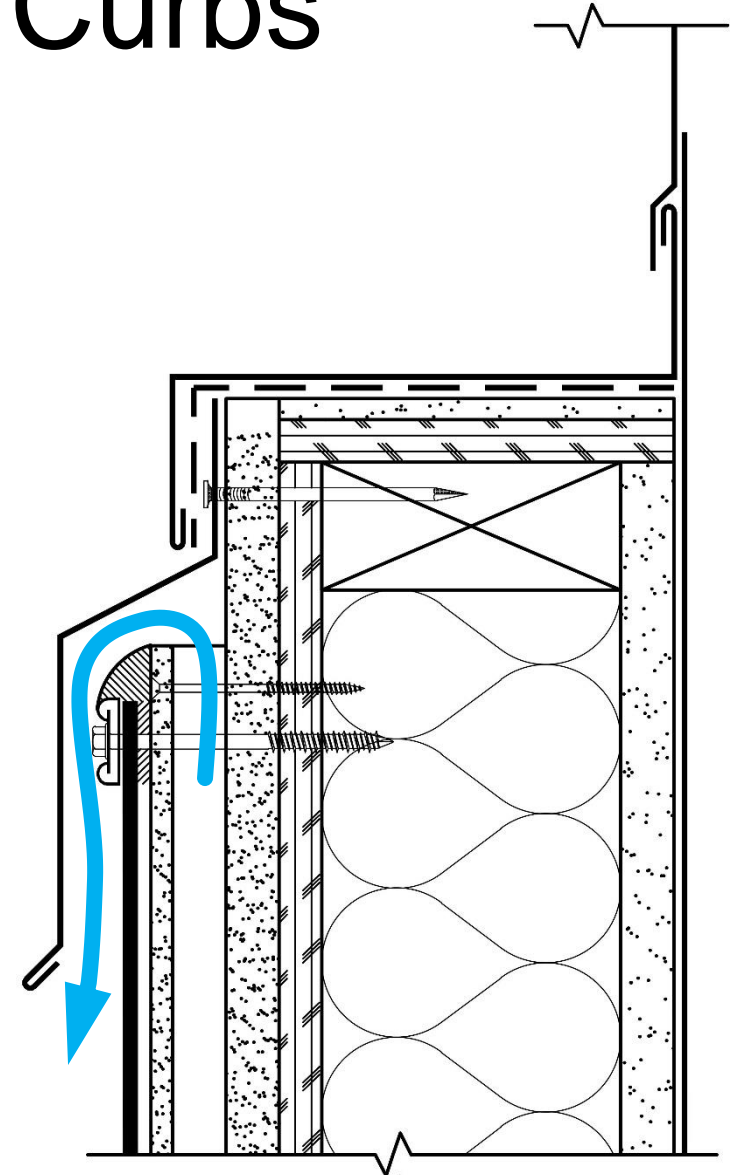
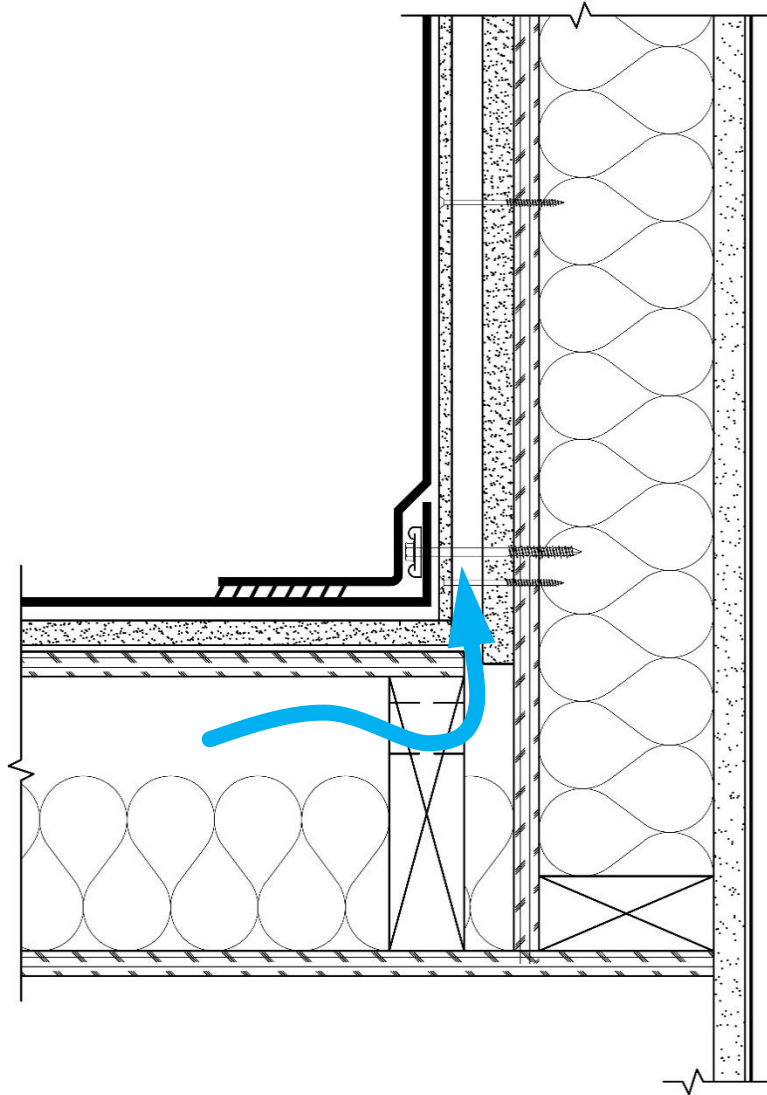
Venting Double Roof Deck With Sloped Framing



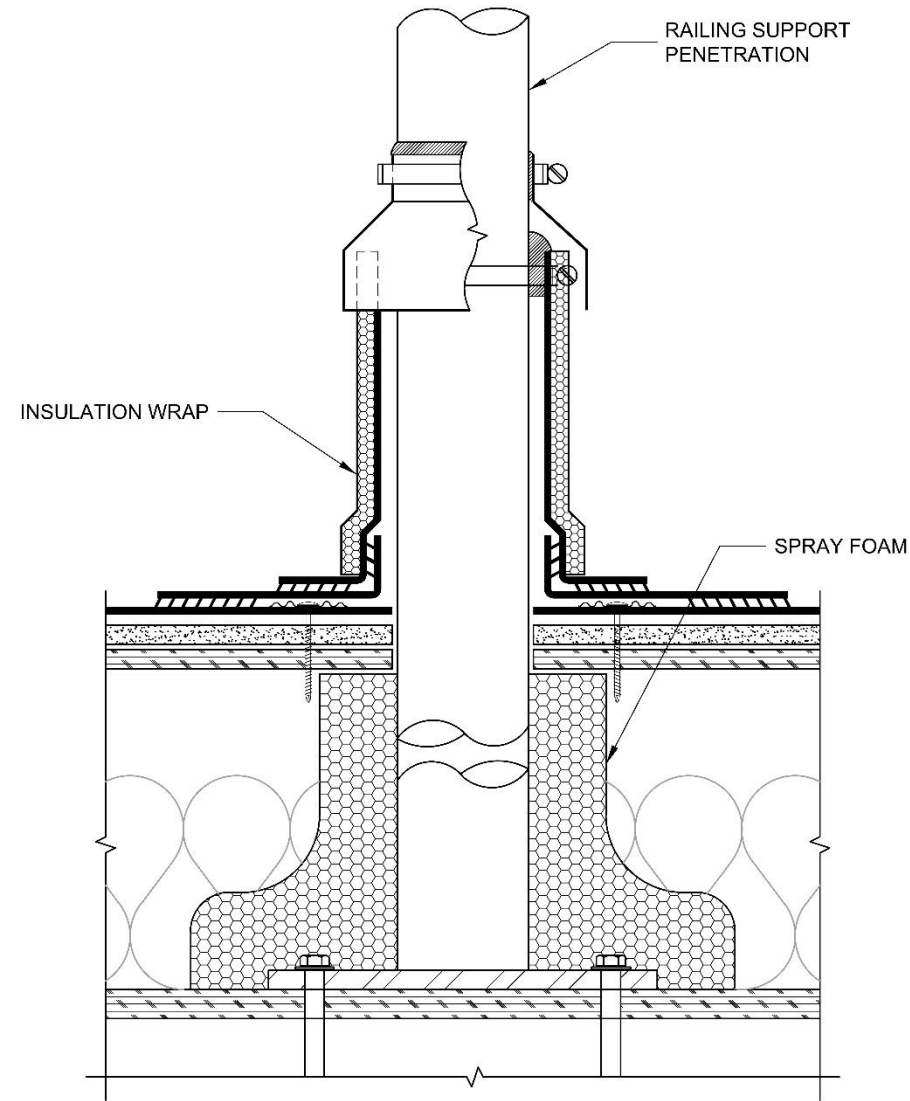
Mechanical
Ventilation



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!

