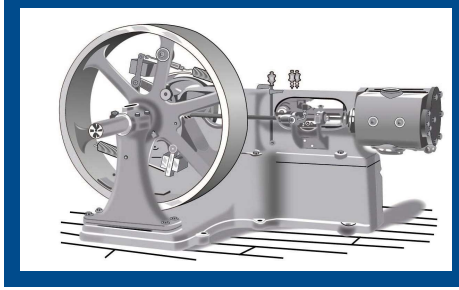

MN Chief Engineers Guild
March Quarterly Meeting

The Case of the Rotting Roofs

March 23, 2021

Michael D. Remington, P.E.

INSPEC®

Agenda / 'Plot'

- The 'Victims' – What Was the Problem?
- The 'Motive' – Why This Design?
- The 'Evidence' – What Was Found?
- Crime Lab Analysis – Computer Modeling
- The 'Verdict' – What Was the Cause?
- The 'Sentence' – How Do You Fix It?
- Lessons Learned

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The ‘Victims’

- **Three Multi-Family Residential Buildings in Minnesota**
- **Less Than 10 Years Old**
- **Low-Slope Non-Ventilated Roofs**

The ‘Victims’

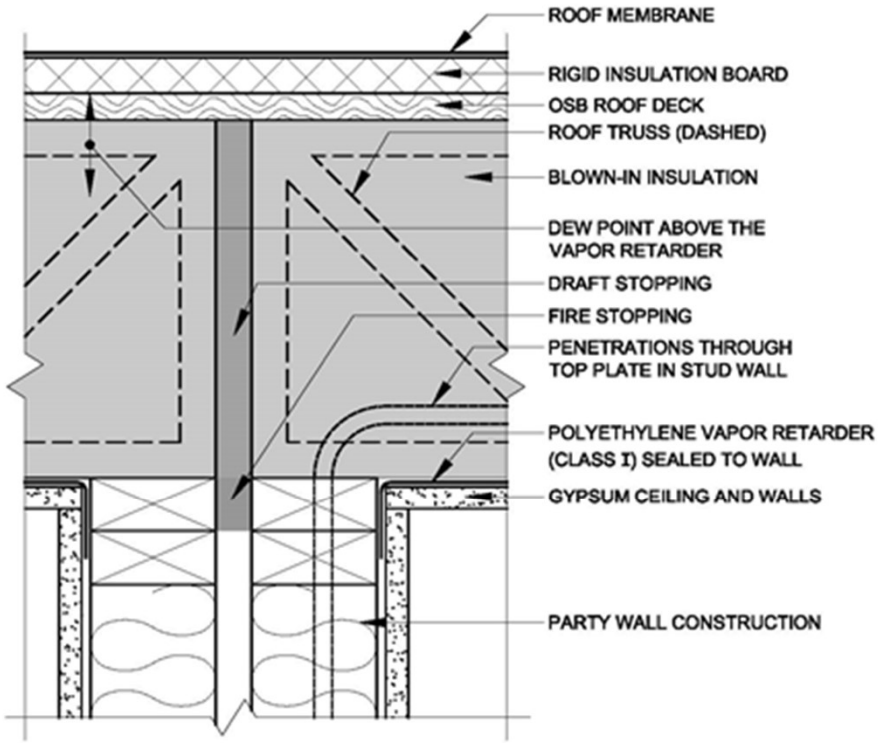
- **Non-Ventilated Low-Slope Roofs**
- **Wood Trusses**
- **Polyethylene Vapor Retarder on Bottom of Trusses Covered with Gypsum Ceiling**

The ‘Victims’

- **Blown-in fiberglass or cellulose insulation filled the truss space from ceiling to bottom of roof deck**
- **Oriented Strand Board (OSB) Installed over Trusses as Roof Deck**
- **Roof Membrane on Top of Deck**

The ‘Victims’

Detail



PROBLEM ASSEMBLY

NO SCALE

BYPASSES IN THE VAPOR RETARDER:

- STUD WALL CONSTRUCTION (DOUBLE IN THIS SITUATION)
- PENETRATIONS THROUGH TOP PLATES IN STUD WALLS
- PENETRATIONS THROUGH CEILING (IE. ELECTRICAL BOXES, SPRINKLER HEADS)

FIGURE 1

The ‘Motive’ of Design

Possible ‘Motive’ of This Design:

- **Minimize Insulation Costs and Still Meet Energy Code**
- **Filling truss space with non-combustible insulation eliminates need for draftstopping required by building code.**

The ‘Crime’

- **Building Occupants Reported Musty Odors and Concerns About Mold**
- **Maintenance Staff Walked the Roofs and Reported Soft Spots**
- **No Signs of Water Intrusion were Observed or Reported**

Evidence from Crime Scene

Invasive Test Openings, Cut Into Roofs

Evidence from Crime Scene

- **Top Portion of Top Chord of Wood Trusses Were Wet and Rotting in Places**
- **Steel Tie Plates on Trusses Were Corroded**
- **Framing Lumber at Exterior Walls Was Wet**

Evidence from Crime Scene

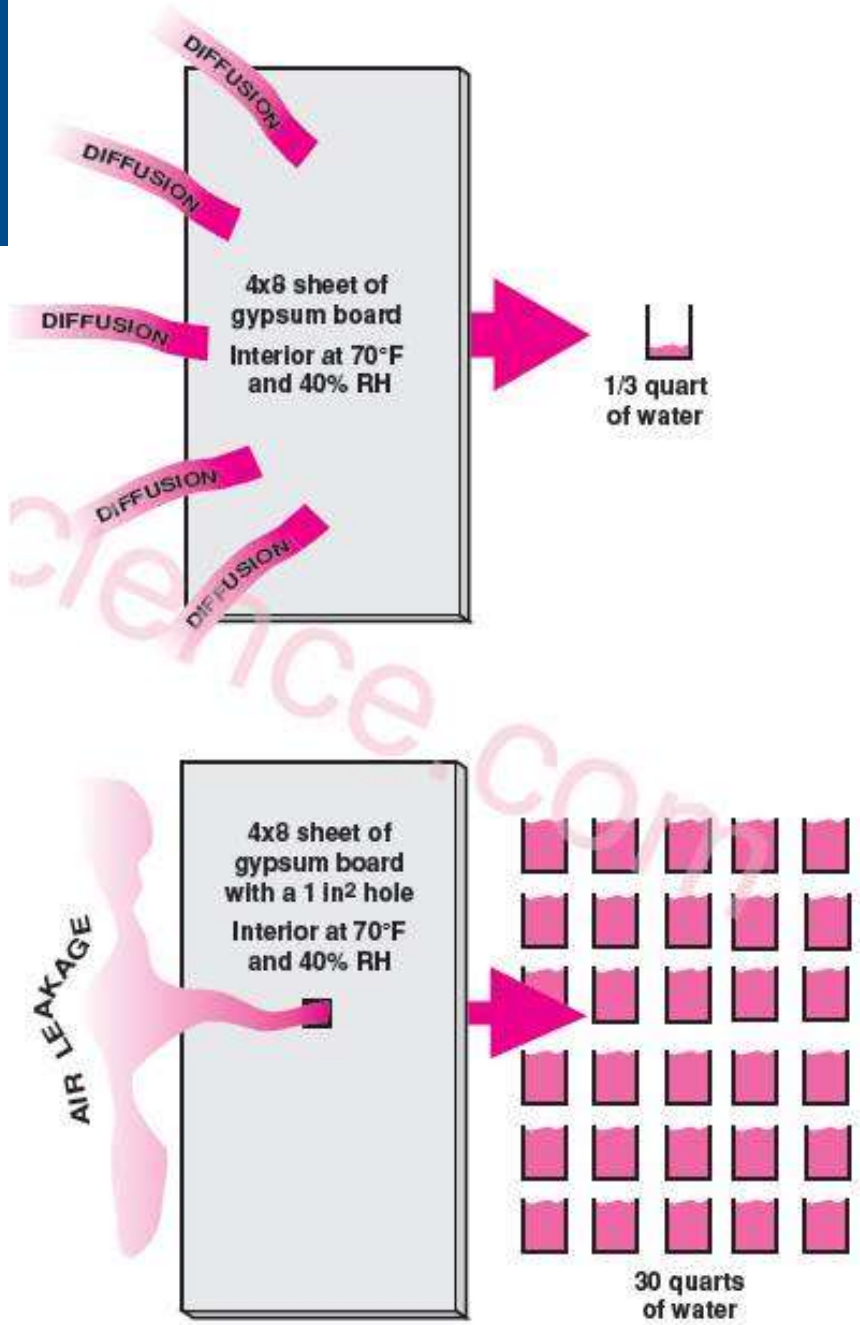
Roof Trusses and Roof Deck Severely Deteriorated in Many Areas

Mystery: Where Was All This Water Coming From?

Background Information

Vapor Drive

- In northern climates vapor drive goes from warmer moist interior space towards colder outdoor space.
- Vapor Retarders are intended to prevent moisture vapor from getting to interior of the building to unheated space.



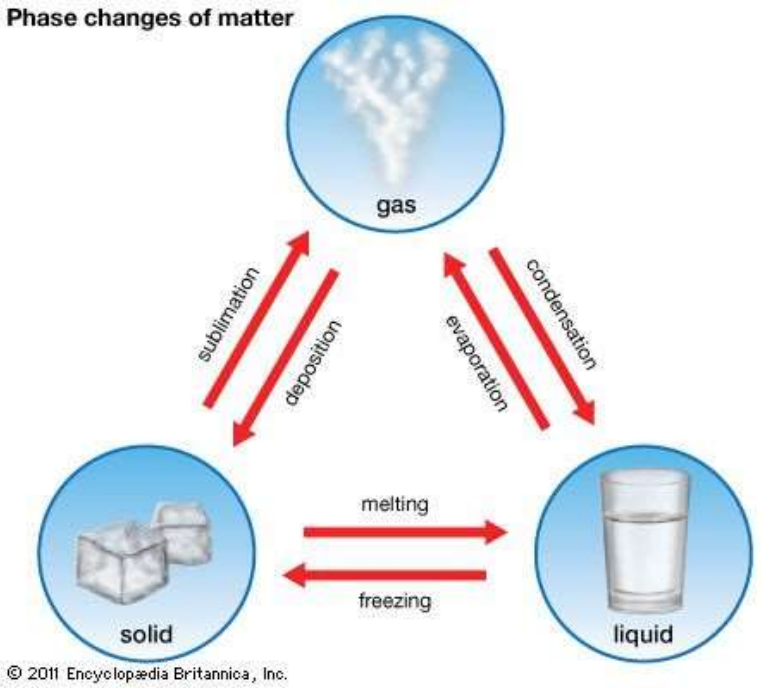
Diffusion vs. Air Leakage

Source: Building Science Corporation 'Builder's Guide'

Background Information

Condensation

- **Definition: Change of State from a Vapor to a Liquid**



Dew Point

Air Temperature in Degrees Fahrenheit

Air Temp °F	% Relative Humidity																		
	100	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10
110	110	108	106	104	102	100	98	95	93	90	87	84	80	76	72	65	60	51	41
105	105	103	101	99	97	95	93	91	88	85	83	80	76	72	67	62	55	47	37
100	100	99	97	95	93	91	89	86	84	81	78	75	71	67	63	58	52	44	32
95	95	93	92	90	88	86	84	81	79	76	73	70	67	63	59	54	48	40	32
90	90	88	87	85	83	81	79	76	74	71	68	65	62	59	54	49	43	36	32
85	85	83	81	80	78	76	74	72	69	67	64	61	58	54	50	45	38	32	
80	80	78	77	75	73	71	69	67	65	62	59	56	53	50	45	40	35	32	
75	75	73	72	70	68	66	64	62	60	58	55	52	49	45	41	36	32		
70	70	68	67	65	63	61	59	57	55	53	50	47	44	40	37	32			
65	65	63	62	60	59	57	55	53	50	48	45	42	40	36	32				
60	60	58	57	55	53	52	50	48	45	43	41	38	35	32					
55	55	53	52	50	49	47	45	43	40	38	36	33	32						
50	50	48	46	45	44	42	40	38	36	34	32								
45	45	43	42	40	39	37	35	33	32										
40	40	39	37	35	34	32													
35	35	34	32																
32	32																		

Condensation

Evidence from Crime Scene

Numerous Bypasses Found in Vapor Retarder:

- **Walls Between Units Interrupted Continuity of Vapor Retarder**

Evidence from Crime Scene

Numerous Bypasses Found in Vapor Retarder:

- **Penetrations Through Top Plate of Walls for Plumbing and Electrical**

Evidence from Crime Scene

Numerous Bypasses Found in Vapor Retarder:

- **Penetrations Through Ceilings for Fire Protection, Electrical Boxes, etc.**

Evidence from Crime Scene

Other Contributing Factors:

- **Ductwork from Dryer Vents and Bathroom Vents Not Properly Sealed in Many Locations**

Hygrothermal Modeling

Definition:

- **Hygrothermal modeling uses a computer program to model the long-term effects of heat and moisture within and through construction assemblies.**
- **The industry-accepted Hygrothermal modeling tool is WUFI.**
- **WUFI is a German acronym which stands for Wärme Und Feuchte Instationär, which translated means heat and moisture transiency.**

Crime Lab Analysis

Traditional methods for analyzing moisture such as the Dew Point Method, the Glaser Diagram, and the Kieper Diagram have significant limitations because they are steady-state and do not factor in the moisture storage capacity in building materials and transient effects of vapor drive.

Crime Lab Analysis

- **Hygrothermal Modeling, in contrast to the traditional methods, looks at moisture levels and temperatures over time and takes into account many variables.**
- **Most importantly, it can show whether the system has a propensity for moisture to build up to damaging levels.**

Hygrothermal Modeling

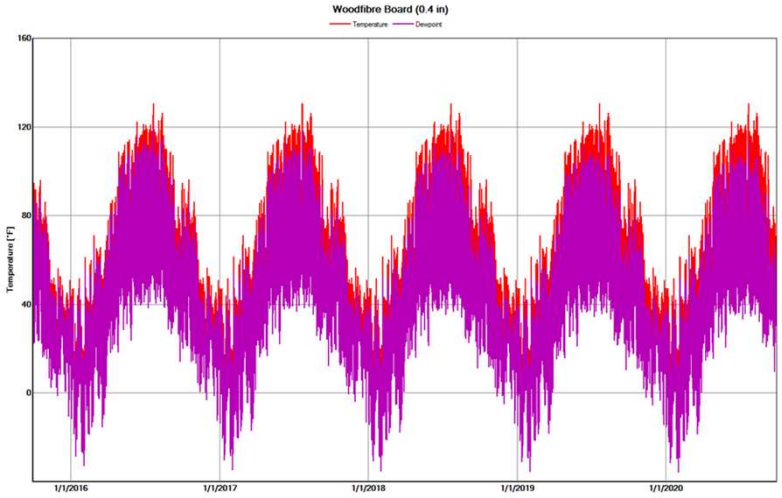
WUFI hygrothermal modeling software:

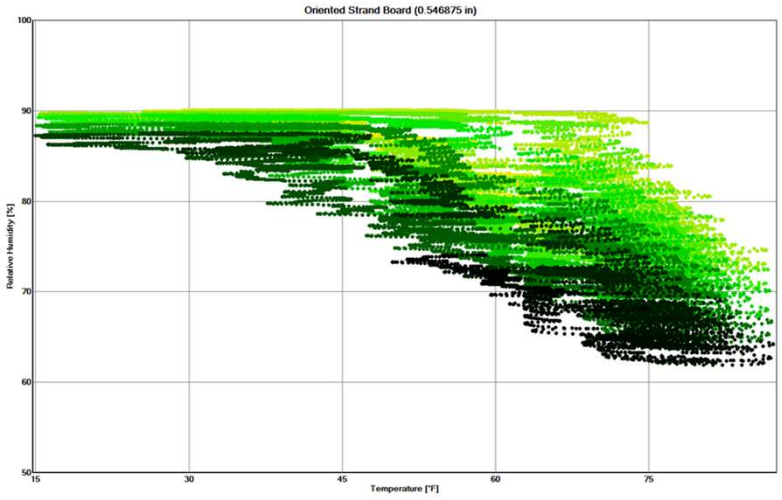
- **Evaluates climate conditions based upon the location and orientation of a building section.**
- **Evaluates material properties based upon the initial conditions, and heat and moisture storage characteristics of each material in a building section.**
- **Complies with the ASHRAE SPC 160P design criteria for moisture control in buildings.**

Hygrothermal Modeling

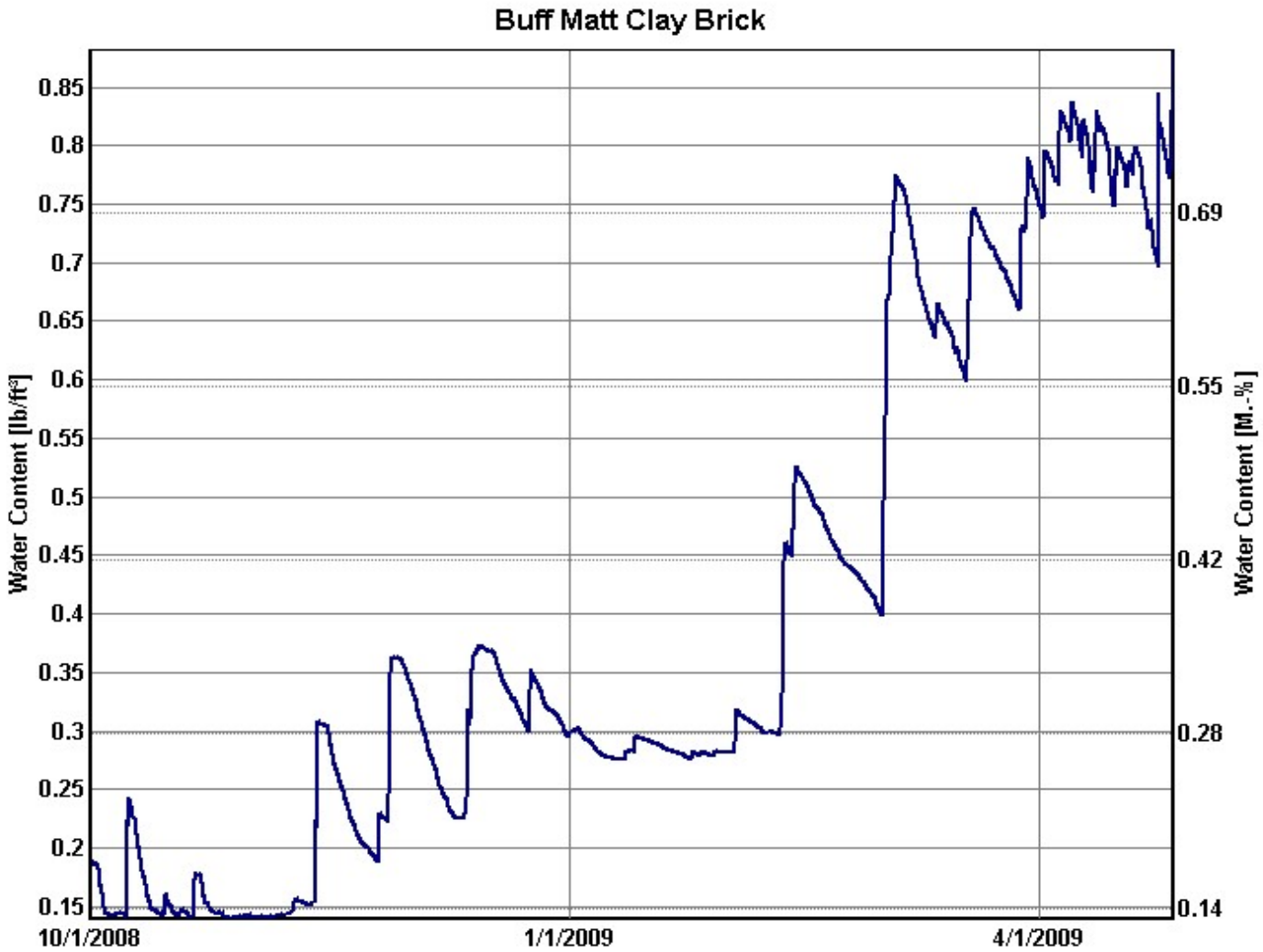
Modeling evaluation results include:

- **Hygrothermal Model Video Analysis and Comparison**
- **Total Water Content in the Building Section**
- **Water Content in Specific Building Components**
- **Temperature, Relative Humidity, and Dew Point Monitoring and Analysis**



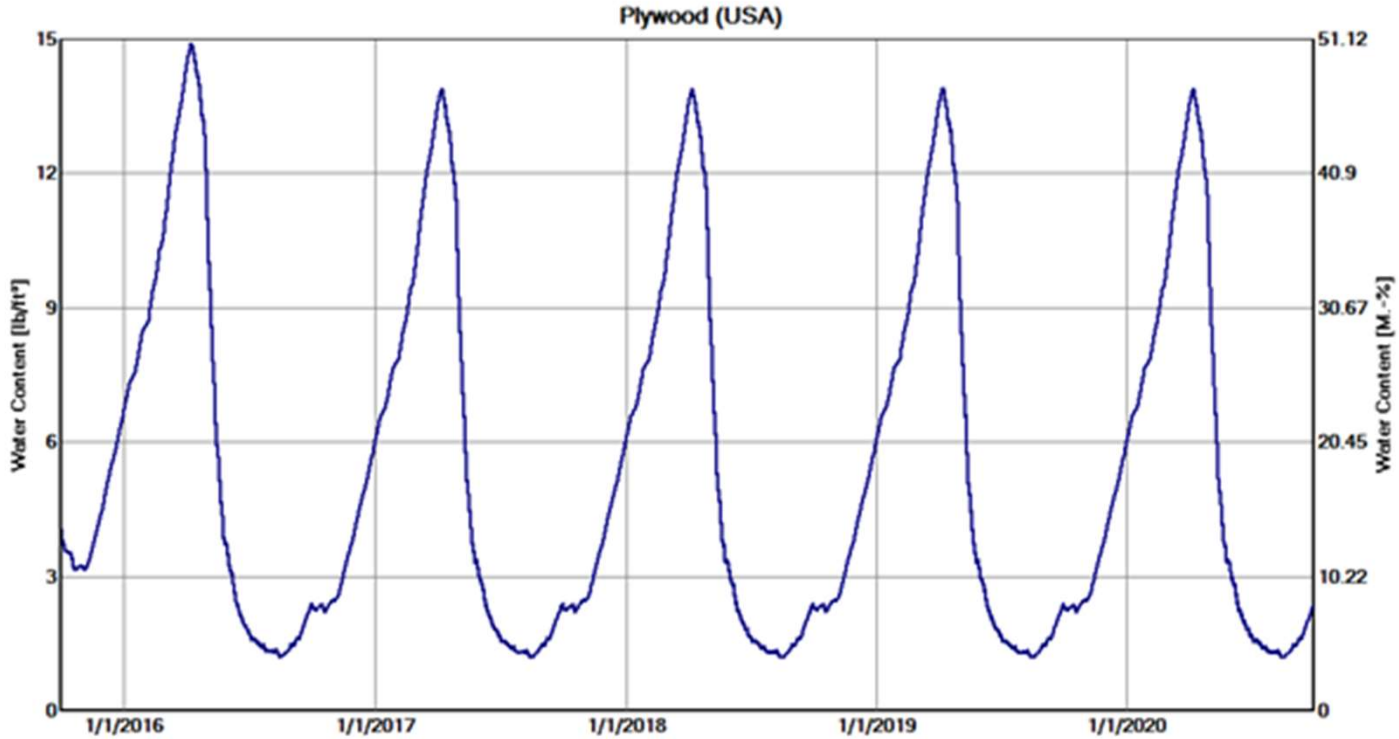


Total Water Content in Specific Building Component



Crime Lab Analysis

Hygrothermal Modeling of Existing Roof System



- **Shows Moisture Content of Roof Deck at 19% for About 40% of the Year Peaking in April.**

The ‘Verdict’

- **It was apparent that warm moist air was travelling through the many bypasses in the vapor retarder from the interior of the building up into the unheated attic space.**
- **This warm moist air was then, at certain times of the year, cooled below its dew point and condensed, resulting in significant amounts of water forming in this space.**
- **This moisture was then causing the rot and corrosion of building materials in this space.**

The ‘Sentence’

- **Need to Replace Entire Roof**
- **Need to Develop a Vapor Barrier that is Continuous (No Bypasses)**
- **Need to Prevent Moisture from Reaching Condensation/Dew Point Temperatures**
- **Need to Repair/Replace Damaged Trusses and Other Materials**

The ‘Sentence’

Three Design Options Were Developed:

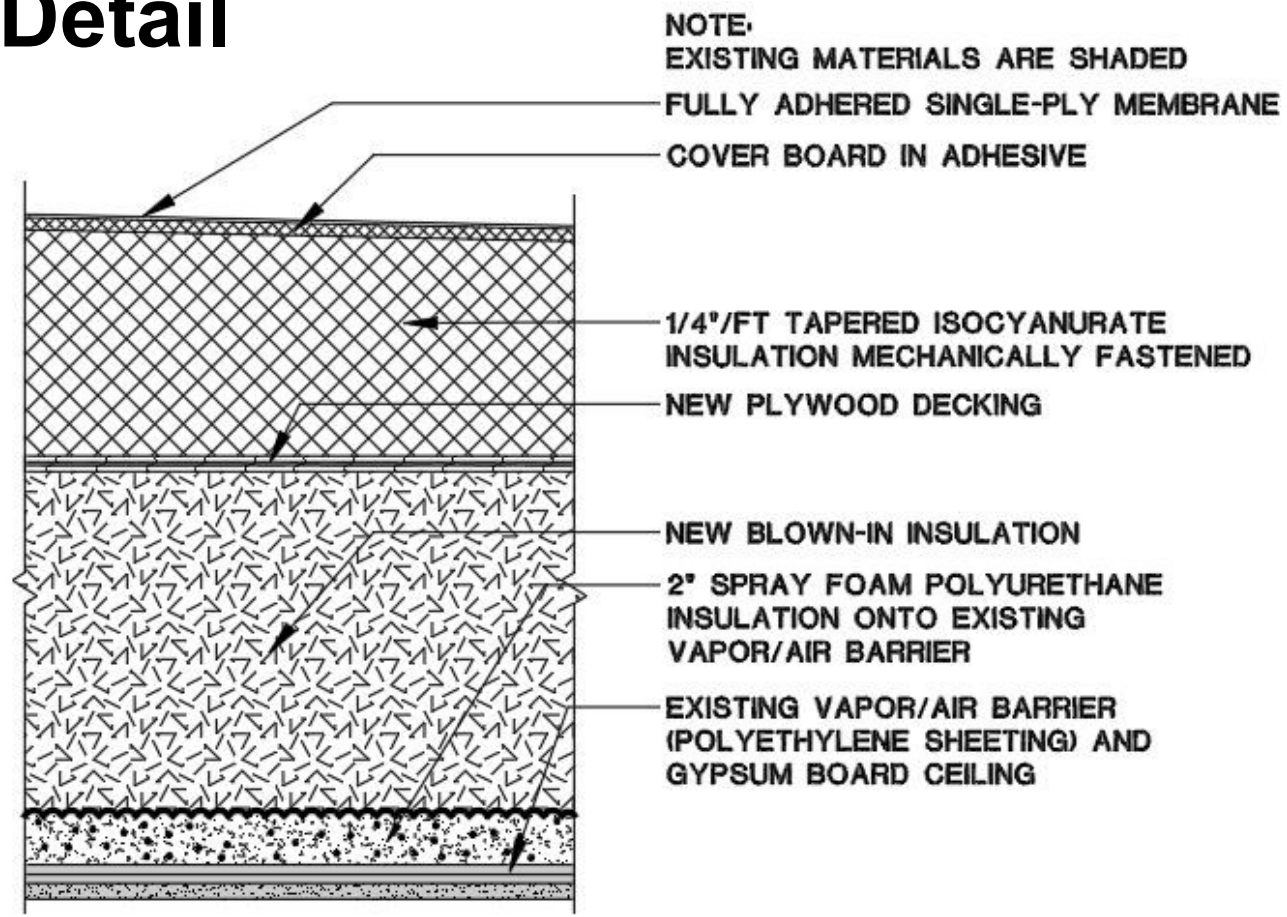
- **Option 1**
  - Create complete vapor/air barrier by installing spray foam over existing poly sheeting and bottom chord of trusses.

The ‘Sentence’

- **Option 1**
  - Would require removal of existing roof membrane and significant portion of wood decking to facilitate removal of existing insulation and installation of new insulation.
  - New tapered insulation and roof membrane would also be installed.

The ‘Sentence’

Option 1 Detail



OPTION 1 (FIGURE 1)

The ‘Sentence’

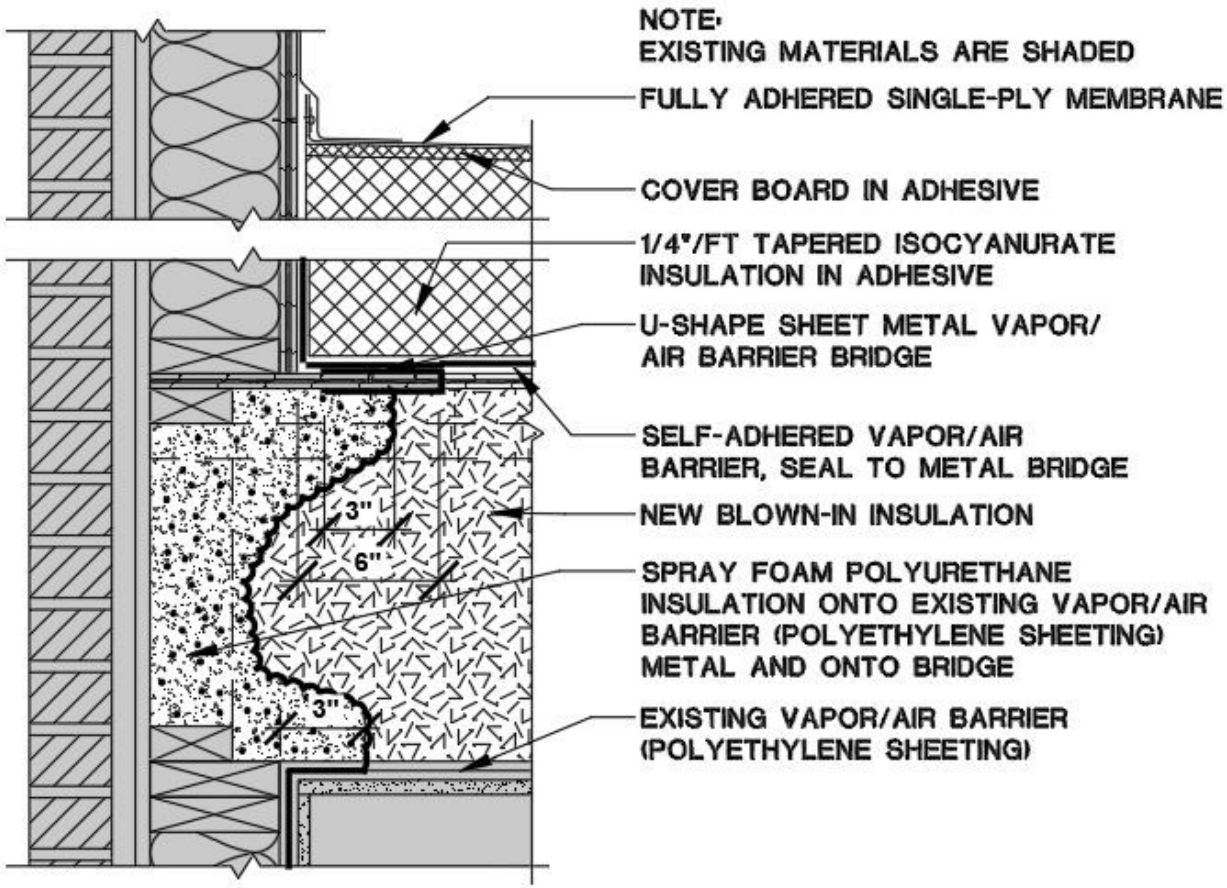
- **Option 2**
  - Remove existing roof membrane down to existing deck.
  - Repair or replace any wet/damaged decking and/or insulation.
  - Install new vapor/air barrier over roof deck.

The ‘Sentence’

- **Option 2**
  - Install spray foam insulation at rim areas of exterior walls to create an effective transition from the vapor/air barrier on the roof deck to the exterior wall vapor/air barrier.
  - Install new tapered insulation to get the dew point/condensation location to occur above the vapor/air barrier.

The ‘Sentence’

Option 2 Detail



OPTION 2 (FIGURE 2)

The ‘Sentence’

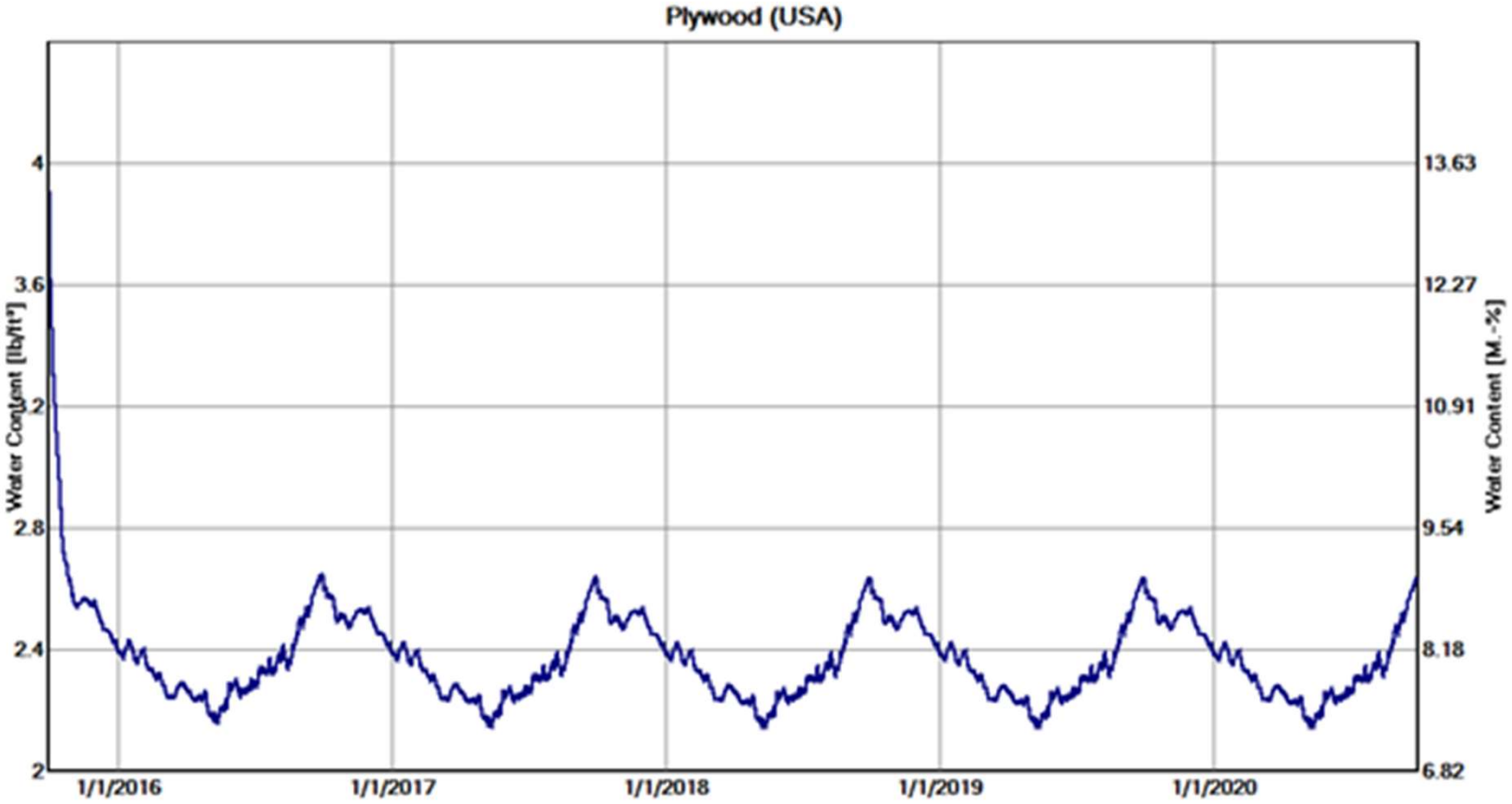
- **Option 3**
  - Remove all existing blown-in insulation in the truss space and install a new sprinkler system to satisfy fire code.
  - Install new roof assembly and insulation.
  - This option was quickly eliminated because the building owner did not want to install new sprinkler system.

The ‘Sentence’

- **Option 2 Was Selected**
  - Best solution to achieve goal of a continuous vapor/air barrier.
  - Exposed all of existing roof assembly to allow for removal and remediation of wet, deteriorated, or moldy components.
  - Maximized reuse of existing roof deck and blown-in insulation that was still in acceptable condition.

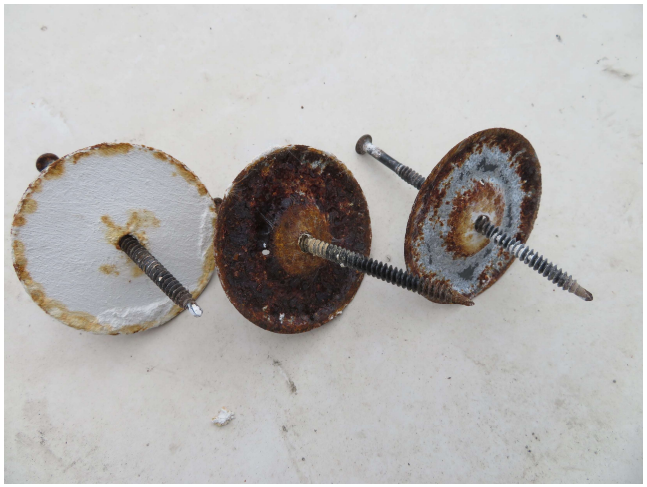
The ‘Sentence’

- **Hygrothermal Modeling of Option 2**



The ‘Sentence’

- **Design/Construction Challenges**
  - Determining damaged areas and acceptable areas of decking and insulation
  - 60 test openings, performed prior to construction to test for moisture content, damage, and mold.



The ‘Sentence’

- **Design/Construction Challenges**
  - Importance of continuous vapor/air barrier transition between roof and exterior walls.
  - Designed U-shaped sheet metal to wrap around structural roof deck edge.

The ‘Sentence’

- **Design/Construction Challenges**
  - Risk of bad weather occurring when roof was removed/exposed.
  - Perimeter work was performed first, small areas exposed at one time which could be covered quickly if needed due to threatening weather.

The ‘Sentence’

Mold remediation paint

The ‘Sentence’

Typical work at roof perimeter

The ‘Sentence’

Z-shaped vapor/air barrier transition metal

The ‘Sentence’

Roof vapor/air barrier at roof perimeter

The ‘Sentence’

Blown-in insulation

But My Building(s) Different!

- **Still Have Air Flow/Vapor Flow Concerns**
- **Still Have Condensation Concerns**
- **Still Have Damage/Mold/Indoor Air Quality Concerns**

Lessons Learned

- **Vapor/Air Barriers Must Be CONTINUOUS**
- **In colder climates, vapor movement is usually towards outside of building.**
- **Condensation can occur where warmer moist air cools below Dew Point temperature.**
- **Hygrothermal Modeling can prevent problems before they occur**
- **A Solid Plan is Critical!**

Questions?

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