Avoiding Condensation Problems 2007 Pacific Building Trade Expo by AIA/CSI

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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

ABBAE 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

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Objectives

- Understand the scientific basis of condensation
- Learn the impacts of condensation including its sources and locations in typical building assemblies
- Understand condensation damages related to:
  - Exterior walls
  - Interior walls
  - Chilled water piping system
  - Indoor swimming pools & spas

My Background

- Civil Engineer specializing in Building Technology
- Forensic evaluation of building failures
- Remedial design of condensation and water intrusion mechanisms
- Peer review of other designers
- Construction monitoring and administration
- Determining ongoing maintenance requirements

Overview

- Address the effects of condensation related water damage leading to mold and indoor air quality
  - Changes in Code IBC 2003 as relates to design of exterior walls
  - Principles of water phases, relative humidity, condensation, vapor retarders and vapor pressure
  - Condensation caused by vapor transmission through interior and exterior walls
  - Condensation caused by chilled water insulation failure.
  - Condensation caused by indoor pools and spas

New Code Changes

- IBC 2003 Section1405.2
- “The exterior wall envelope shall be designed and constructed in such a manner as to prevent the accumulation of water within the wall assembly…..”

- UBC 1997 Section 1708 (b)
- “Flashing and Counter flashing-Exterior openings exposed to the weather shall be flashed in such a manner as to make them weatherproof. ”

New Code Changes

- IBC 2003 Section1405.2
- The new code places emphasis on “design” and “construction” properly to prevent water intrusion

- UBC 1997 Section 1708 (b)
- The old code was more vague and relied more on “proper construction” of the wall.

- New code imposes more liability on designer

IBC 2003

- **1403.3 Vapor retarder.** An approved vapor retarder shall be provided.
- **Exceptions:**
- 1. Where other approved means to avoid condensation and leakage of moisture are provided.
- 2. Plain and reinforced concrete or masonry exterior walls designed and constructed in accordance with Chapter 19 or 21, respectively.

International Energy Conservation Code

- **502.4.3 Sealing of the building envelope.** Openings and penetrations in the building envelope shall be sealed with caulking materials or closed with gasketing systems compatible with the construction materials and location. Joints and seams shall be sealed in the same manner or taped or covered with a moisture vapor-permeable wrapping material. Sealing materials spanning joints between construction materials shall allow for expansion and contraction of the construction materials.

Condensation Relevant Terminology

- Water Phases
- Relative Humidity
- Condensation
- Relative Humidity
- Condensation
- Water Vapor Movement
- Diffusion / Permeability

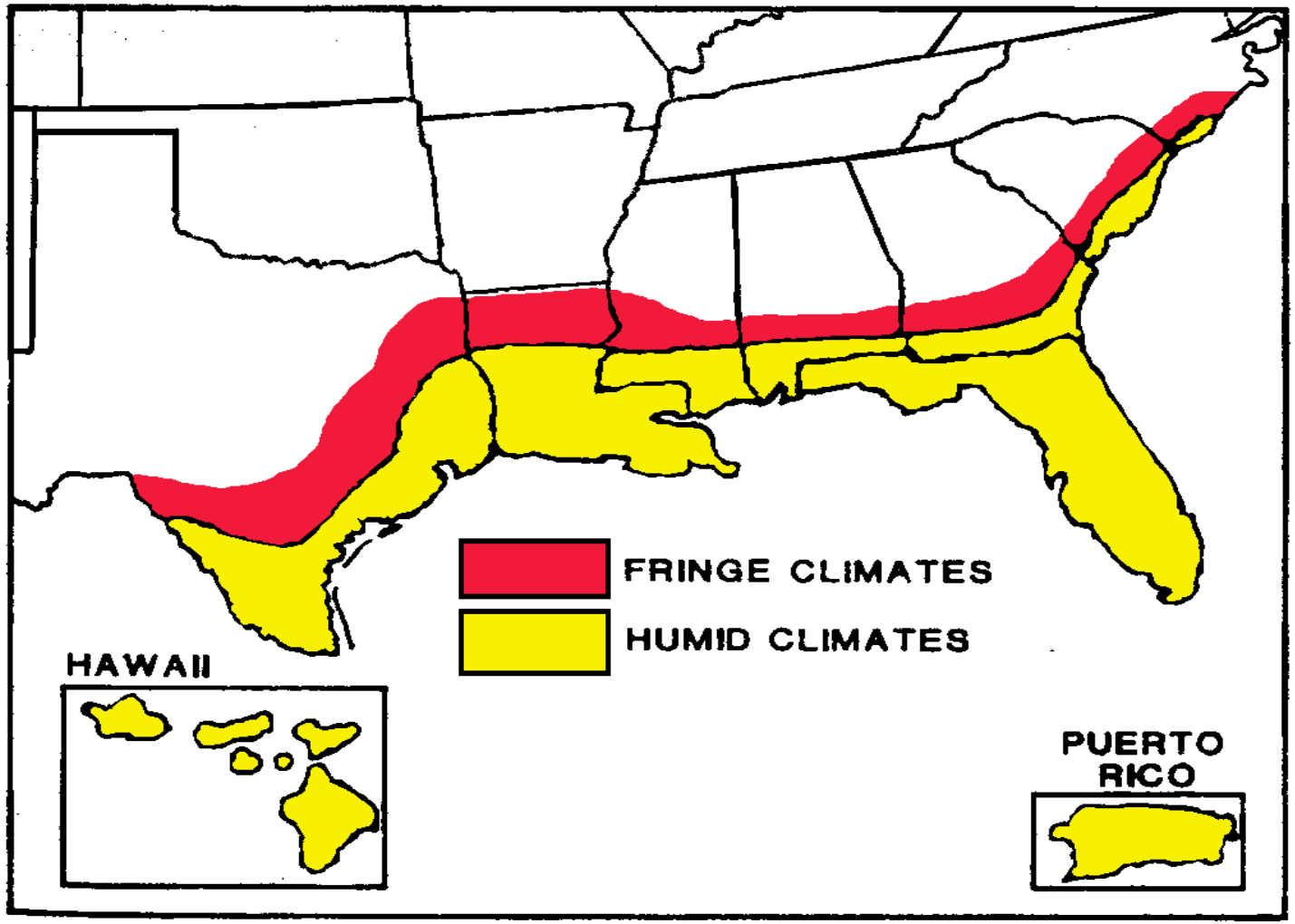
Water Phases

- Water can exist in three phases
  - Ice (Only in your Mai Tai in Hawaii)
  - 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 in the form of condensation

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!!!
  - Hawaii has many sources of humidity, both external and internal
- Relative humidity is expressed as a percentage: 100% humidity means that the air is saturated at that temperature

•Chart for dew point



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”
- This temperature is relatively high in humid Hawaii
- Condensation occurs when humid air meets cold surfaces such as air conditioned walls, chilled water lines, indoor pools

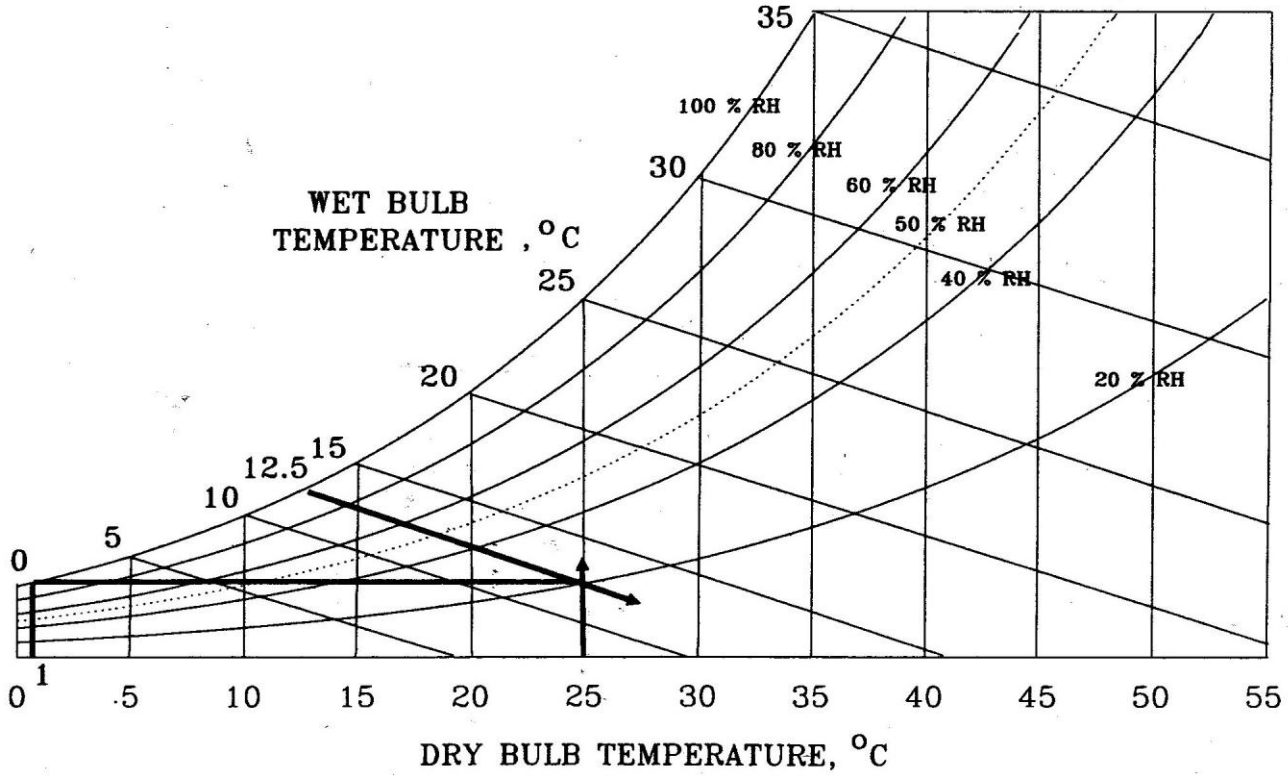


FIG. A4—Calculation of relative humidity and dew point temperature from psychrometric measurements.

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 pressures
- The amount of pressure that water vapor exerts is a function of temperature and relative humidity
- Water vapor will flow from the place of higher vapor pressure, to the place where the vapor pressure is lower
- In Hawaii, this occurs in two typical conditions:
  - Through exterior walls (outside high vapor pressure, inside low vapor pressure)
  - Through a bathroom or other wet condition to a cooler and drier condition such as a bedroom

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

- The speed of water vapor transmission through a material, induced by the vapor pressure difference between two sides.
- Measured in “perm” units
- Permeance ratings under 0.5 = vapor retarder

Permeability

- The speed of vapor transmission through a flat material (as opposed to an assembly)
- Example, permeability of sheet rock (as opposed to a wall assembly)
- Measured in “perm-inches”

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 ft²)	0.5	
Asphalt (hot applied, 3.5 lbs/100 ft²)	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, 3/8 in. thick)	50	
Hardboard (standard, 1/4 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, 1/4 in. thick)	0.7	
Plywood (Douglas fir, interior glue, 1/4 in. thick)	1.9	
Wood, sugar pine		0.4 - 5.4

Permeance and permeability of typical building materials – the higher the number, the more moisture that passes through

Areas Susceptible to Condensation

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

Condensation in Exterior Wall Assemblies

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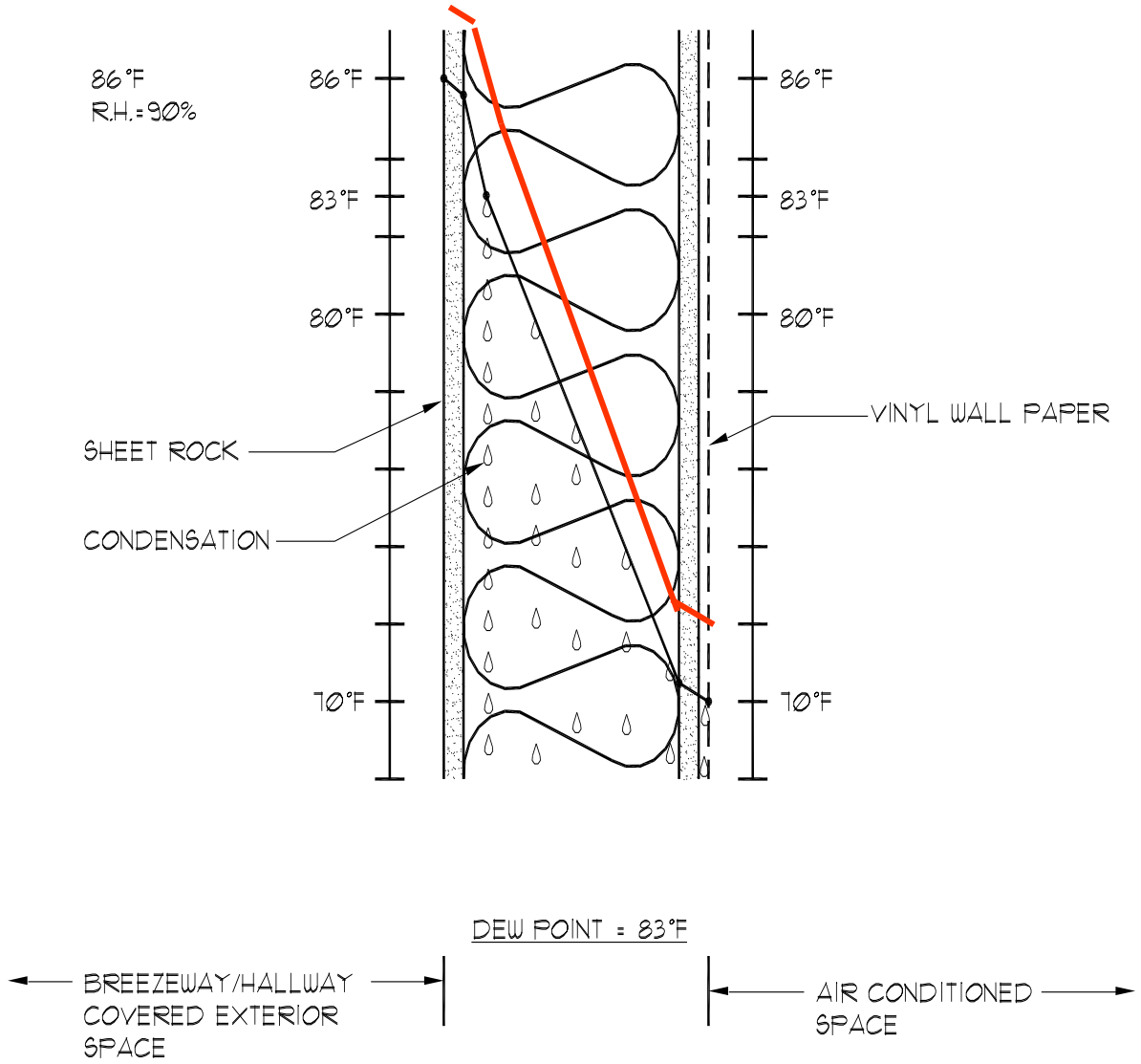
Hidden Mold – Exterior wall

Removal of a small area displayed evidence of some real problems

Fully suited technicians removed wallpaper – note mold due to moisture collection at face of wall paper

Mold on the wall paper and in the wall cavity



WHERE CONDENSATION OCCURS

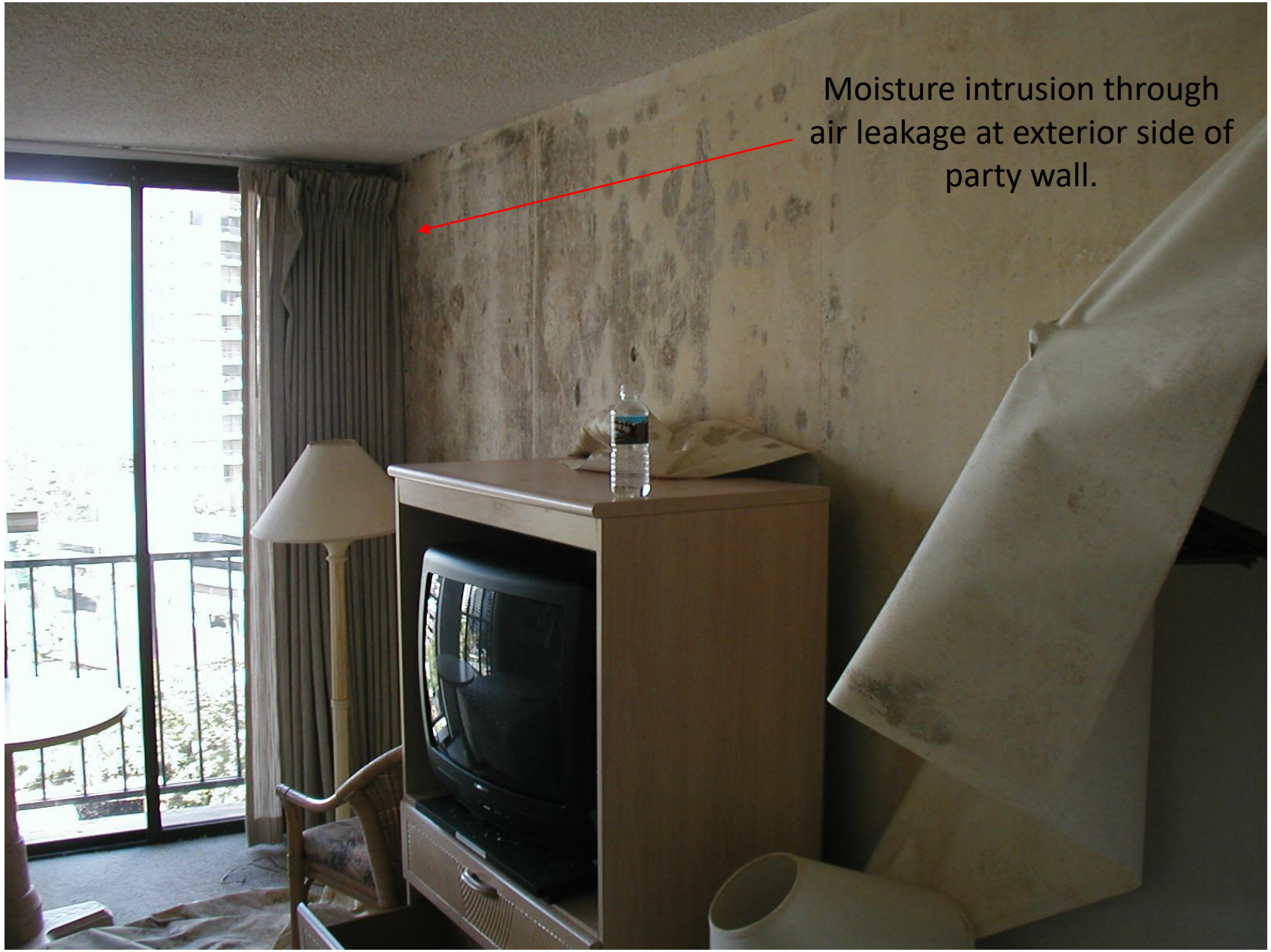
WHERE CONDESATION OCCURS

Case Study of Condensation (Hawaii Cooling Climate) Example of Condensation in Hotel Party Wall

Case Study

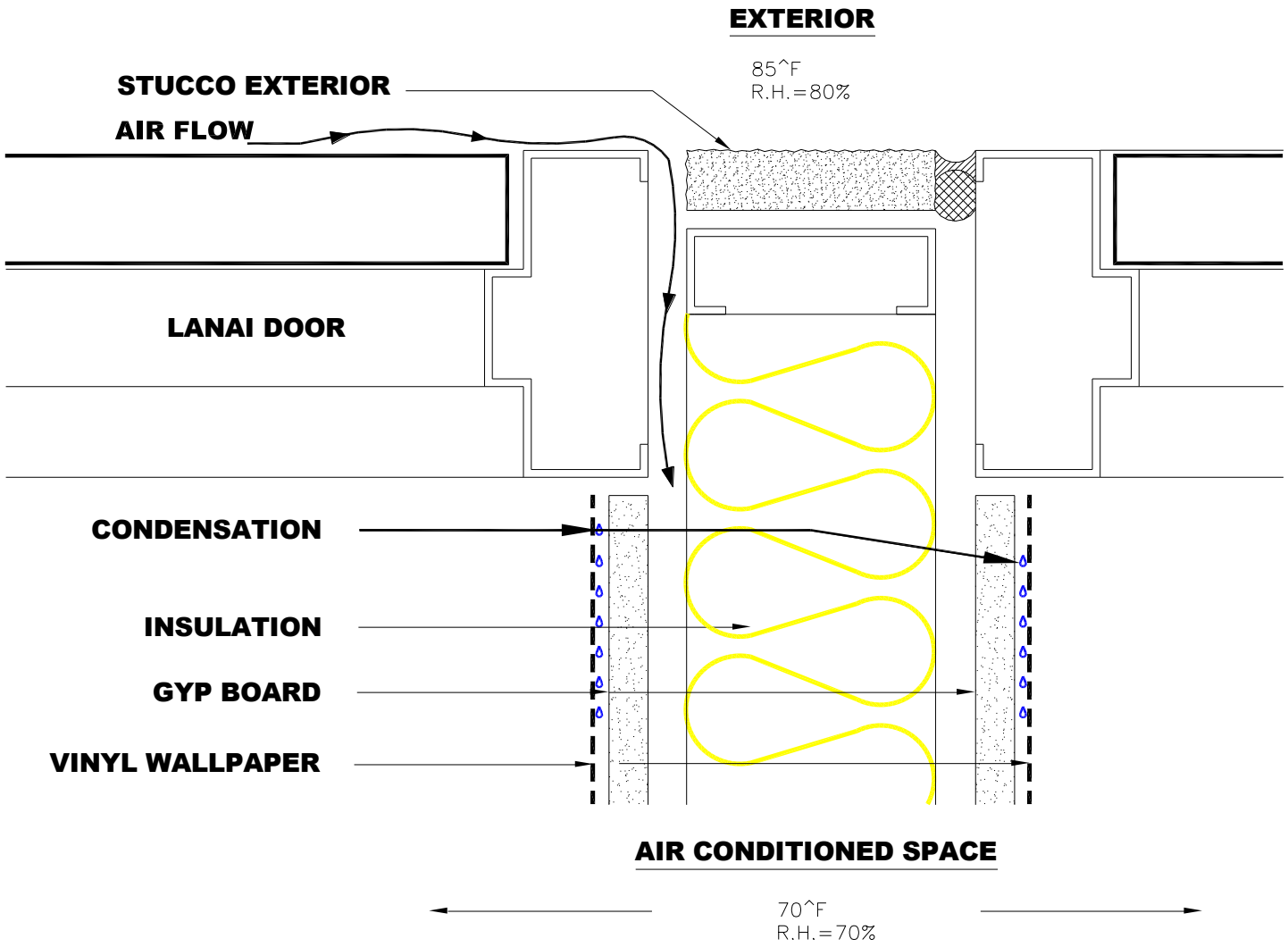
- Honolulu, Hawaii hotel.
- Air leakage through failed sealant joint between lanai door and exterior wall.
- Condensation between hotel party walls.
- Calculate how much condensation (gallons) of water accumulates on the wall in 1 week time span.

Condensation between hotel party walls



Vinyl Wallpaper

Condensation Due to Air Leakage



Moisture Trapped in a Shared Wall Cavity

- Gaps near an exterior door allow warm humid air to flow into wall cavity.
- Affected wall area 10’x8’.
- Outside temperature and relative humidity were 85F and 80% respectively.
- 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/ft^2/hr/in. Hg)

Moisture Trapped in a Shared Wall Cavity

Step 1: **Area = 10'x8' = 80 ft^2**

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 # 1: 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:**

VT= 80 ft² x 168 hr x 0.4523 in.Hg x 50 perm

= 304,389 grains of water

= 43.5 pounds of water

= 5.24 gallons of water (in 1 week)

Condensation in Interior Bathroom or Spa Wall Assemblies

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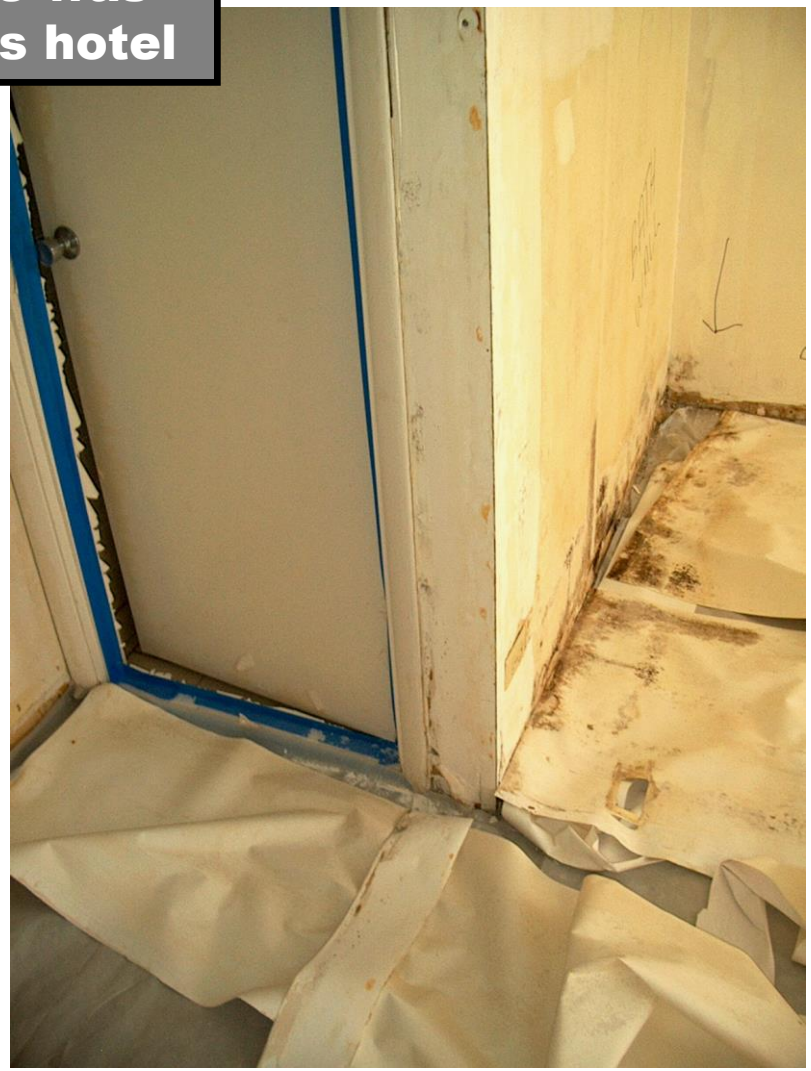
Condensation on an interior to Interior wall

Source of moisture was the bathroom in this hotel



View of interior bathroom wall from the bedroom side, after wall paper was removed. Note mold below

Condensation in Chilled Pipe Assemblies

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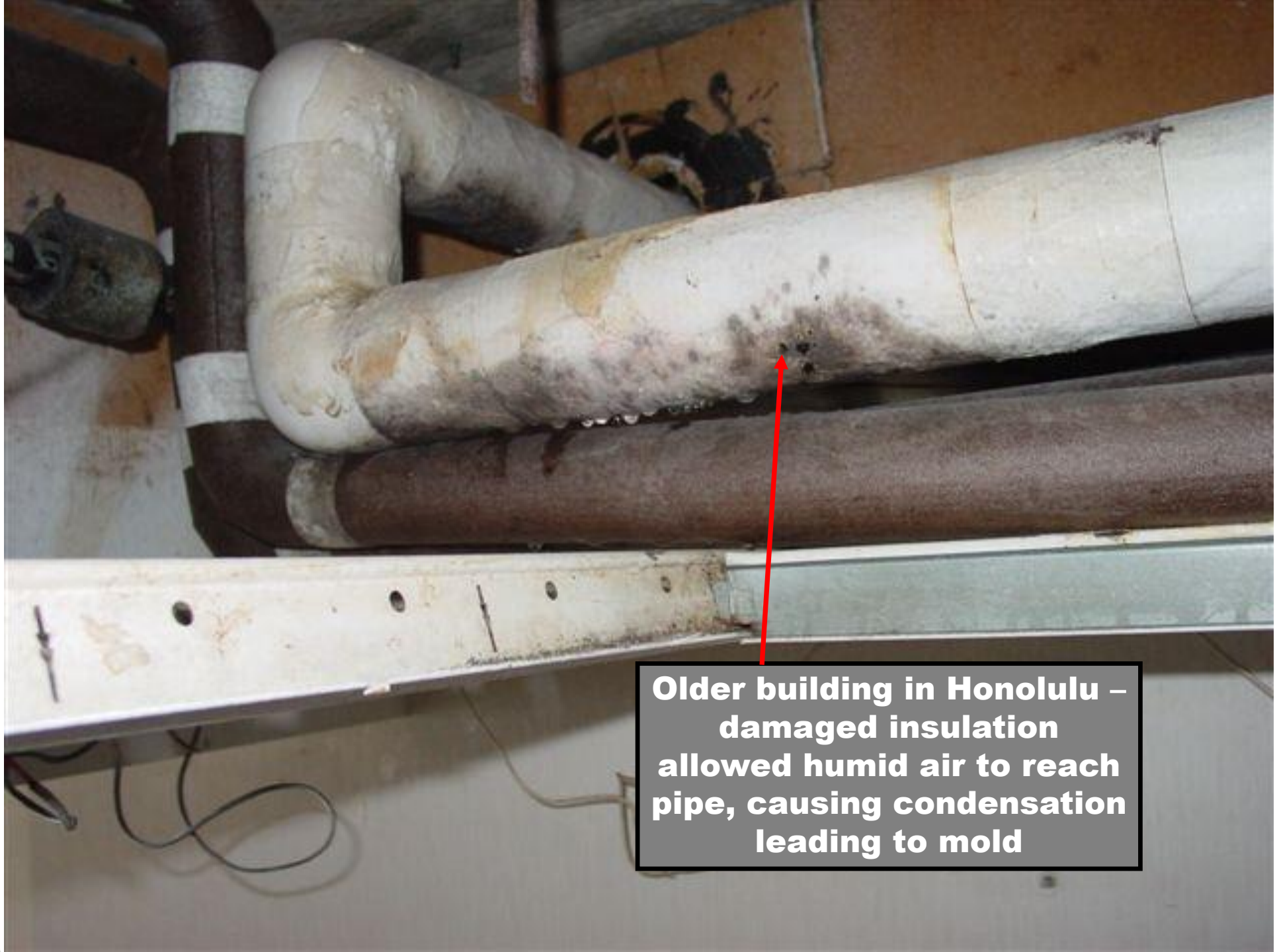

Older building in Honolulu – damaged insulation allowed humid air to reach pipe, causing condensation leading to mold

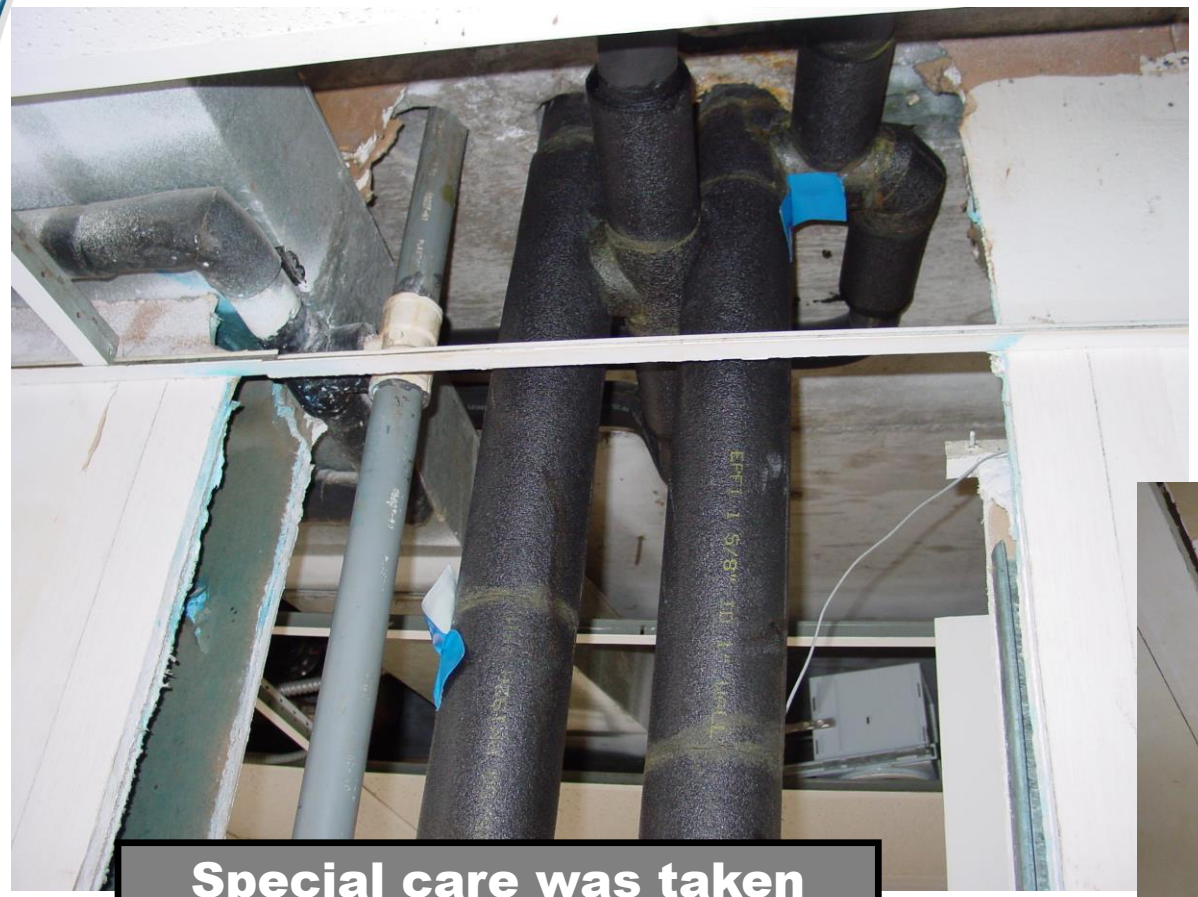
Older building – fan coil unit created condensation, rust and mold

Same building – note gap where there is no insulation, as pipe passed through floor

In a failed attempt to close the gaps, foam injection was attempted in the past

Past attempts to cover pipes with an extra layer of fiberglass insulation also proved unsuccessful

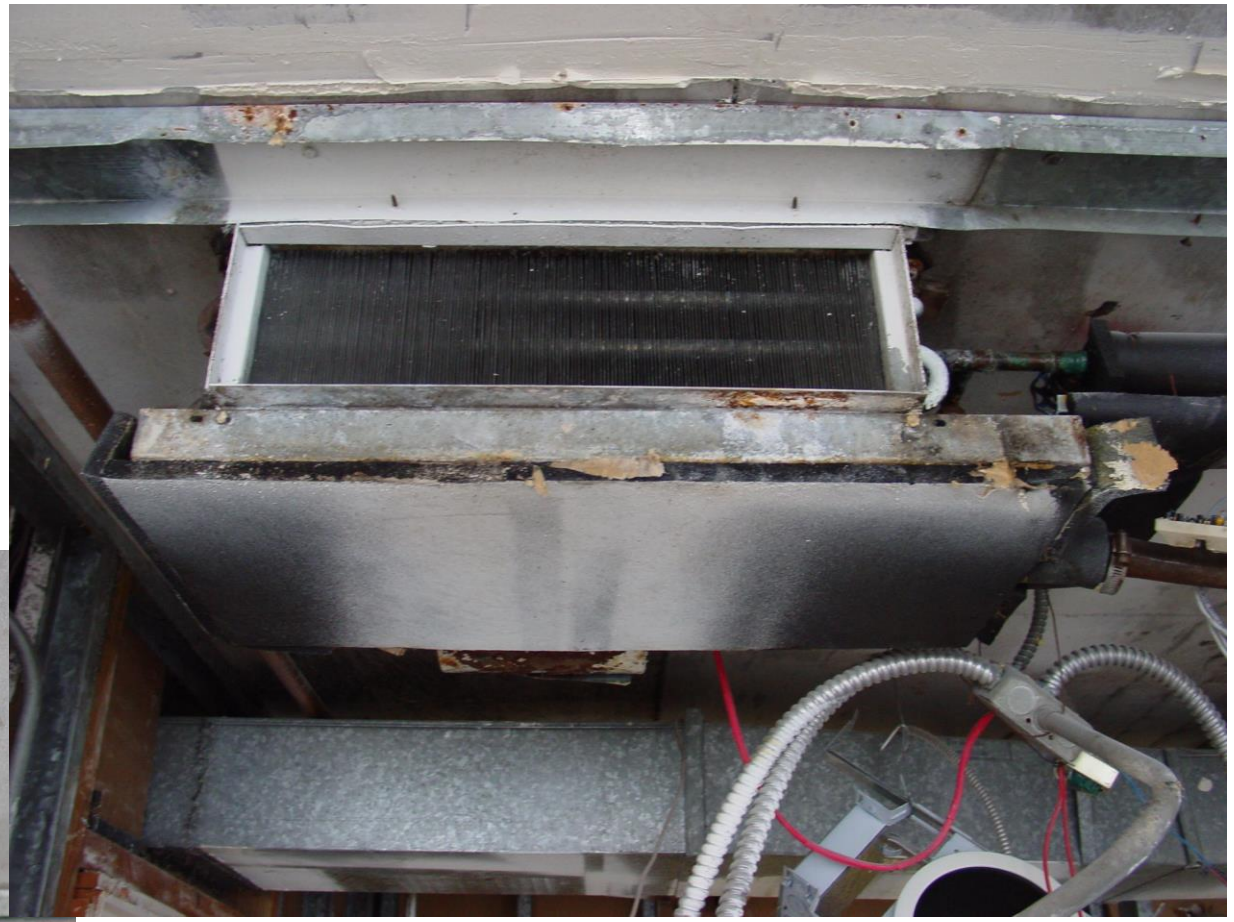
When insulation was removed, rust was evident. Note that some openings in floor were larger than others



Special care was taken during repairs, to place insulation properly

Joints, turns and penetrations were carefully repaired

Condensate pans and branch line treatment. Condensate drain and overflow drain



New building – note two different kinds of insulation makes the joint susceptible

Condensation Problems with Indoor Pools and Spas (warming climate)

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Ceiling paint is rapidly blistering

Equipment Room of an Indoor Pool. Note staining. Moisture is condensing between roof and ceiling.

Is this Really a Leak?

Other Areas Susceptible to Condensation

- Compact roof assemblies, i.e., no attic.
- Wall assemblies with no ventilation or vapor barrier.
- OSB sheathing materials are more susceptible to damage.
- Hardboard siding.

Questions?