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Catastrophic Failures and the Net Effect of Design and Construction Errors on Moisture Management, Resilience and the Built Environment

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Small Errors. Catastrophic Outcomes.

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Learning Objectives

1. Recognize how compounding design and construction flaws contribute to major building and HVAC system failures affecting moisture control and resilience.
2. Interpret case study evidence to identify key failure mechanisms and understand the role of building envelope and HVAC interactions in catastrophic system outcomes.
3. Apply forensic insights to strengthen early-phase design reviews, improve construction oversight, and implement risk mitigation strategies for climate- and energy-resilient buildings.
4. Identify critical building code requirements related to minimum air leakage performance for building enclosures.

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Section 1: Air Leakage Standards: What the Codes Require

Commercial Air Leakage Rates

Standard / Organization	Maximum Air Leakage Rate
ASHRAE 90.1-2022	0.35 CFM/SF @ 75 Pa
2024 IECC	0.35 CFM/SF @ 75 Pa
2021 IECC	0.40 CFM/SF @ 75 Pa
2020 and 2023 FBC-EC	0.40 CFM/SF @ 75 Pa
IgCC (Green Code)	0.25–0.35 CFM/SF @ 75 Pa
USACE / GSA	0.25 CFM/SF @ 75 Pa
PHIUS (Passive House)	~0.08 CFM/SF @ 75 Pa

Section 1: Air Leakage Standards: What the Codes Require

Residential Air Leakage Rates

2020 and 2023 FBC-EC:

- Climate Zones 1 and 2: **7.0 ACH @ 50 Pa**
- Climate Zones 3 through 8: **3.0 ACH @ 50 Pa**

Section 2: The Pressure Context: Why Small Numbers Matter

- Windows are tested at 300 Pa
- Commercial buildings are tested at 75 Pa
- Residential buildings are tested at 50 Pa
- **HVAC-related moisture and mold problems begin at approximately**

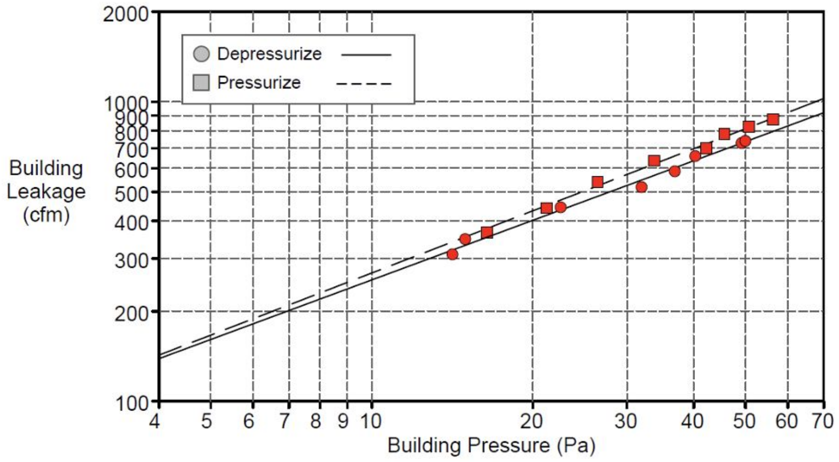
  5 Pa

Key Takeaway - The pressures that cause catastrophic moisture damage are not the pressures we test at. They are an order of magnitude smaller and they operate continuously, every hour of every cooling season, until the damage becomes visible.

Section 2: The Pressure Context: Why Small Numbers Matter

House Tightness Test Details

	Depressurization	Pressurization	Average
Test Results at 50 Pascals:			
Airflow (cfm50)	736 (+/- 3.6 %)	813 (+/- 2.5 %)	775 (+/- 2.2 %)
Air Changes per Hour 50 (1/h)	5.98	6.60	6.29
cfm50/ft² Floor Area	0.9934	1.0972	1.0453
Leakage Areas:			
Canadian EqLA @ 10 Pa (in²)	74.8 (+/- 10.4 %)	78.8 (+/- 9.4 %)	76.8 (+/- 7.0 %)
LBL ELA @ 4 Pa (in²)	39.4 (+/- 17.2 %)	40.5 (+/- 15.3 %)	40.0 (+/- 11.5 %)
Building Leakage Curve:			
Flow Coefficient (C)	55.6 (+/- 27.7 %)	54.9 (+/- 24.3 %)	55.3 (+/- 18.4 %)
Exponent (n)	0.660 (+/- 0.076)	0.689 (+/- 0.065)	0.675 (+/- 0.050)
Correlation Coefficient	0.99338	0.99557	
Test Standard:	E779		
Test Mode:	Depressurization and Pressurization		



Date of Test: 12/01/22 Test File: lbfg i360 12_1_22tst

Section 2: The Pressure Context: Why Small Numbers Matter

- *What is most damaging?*
- *How does ASTM E779 test requirements compare?*

Section 3: The Central Question: What Caused the Failure?

The First Inclination Is Often Wrong

When a building encounters a catastrophic moisture and mold problem after passing an air leakage test, the first instinct is _______?

Before Reacting to This Inclination, You May Ask………..

Section 4: Repeatability: The Scale of the Problem in Domicile Housing

HVAC - Planned Openings

Condition 1 - Wall: *"How often is moisture risk through PTAC (4.5 SF) and VTAC (13.5 SF) louvered openings evaluated beyond the perimeter seal: At the OA duct damper and the internal condenser-to-room boundary - under the wind, mechanical, and stack pressures that drive infiltration continuously at 5 Pa or less?"*

Condition 2 - Ceiling: *"How often is moisture risk from unbalanced airflow evaluated across the ceiling plane: At supply registers, exhaust grilles, and exhaust fans - under the wind, mechanical, and stack pressures that drive infiltration continuously at 5 Pa or less?"*

Section 5: DOAS - The Attempted Solution

The Professions Typical Response to Both Conditions is to Install a DOAS and Pressurize the Corridor

Does this Address Condition 1 - Wall or Condition 2 - Ceiling?

Section 6: The AirTight Ceiling Plane Challenge: When Sealant is Not Enough

- Damage patterns indicate that sealant is not enough.
- When operational pressure measurements (OPMs) indicate negative pressures across the ceiling plane.
- When living space depressurization to -50 or 75 Pa and pressure pan measurements indicate connectivity to the attic or buffered unconditioned space.

Section 7: Transition to Case Studies

"The following case studies reflect the influence of mechanical openings "

"It is also important to note that one issue alone does not cause a catastrophic failure.

Section 7: Three Case Studies, Three Building Types, Two Climate Zones:

- Case Study 1:Gulf Residence Custom Home, **Climate Zone 2A**
- Case Study 2:Limited Service Hotel, **Climate Zone 3A**
- Case Study 3: Multi-family Apartment, Central Florida, **Climate Zone 2A**

Gulf Residence Custom Home

Case Study 1 - Climate Zone 2A

Project Context

Location Details:

Hot and Humid environment within Climate Zone 2A.

Project Focus:

Causes, mechanisms, and pathways contributing to moisture damage, including corrosion and mold growth

Gulf Residence Custom Home

Exterior Elevation Views

Key Takeaway:

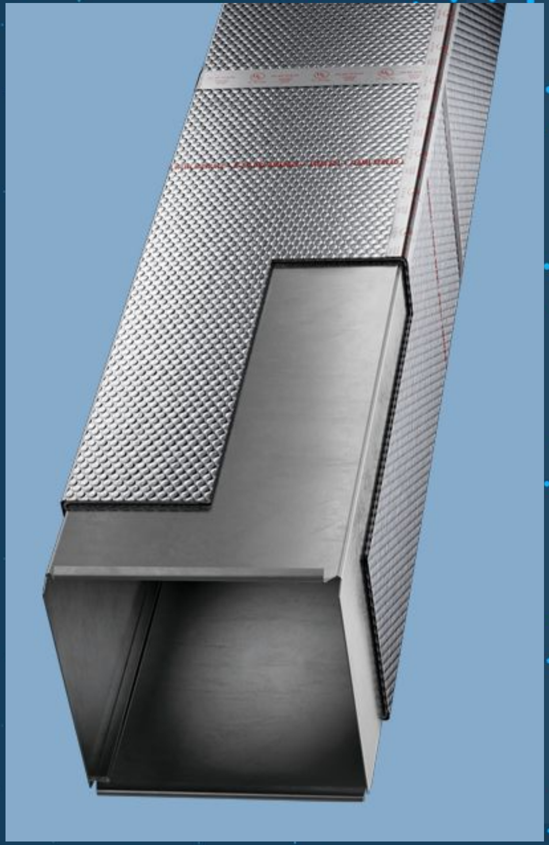
- No single defect caused the outcome. Each deficiency compounded the others. Errors are ranked by their contribution to the overall damage.

Insulated Ductwork - Condensation and Contributing Conditions

Observed Issues:

- Support straps not enclosed/wrapped separately
- Transverse joints misaligned with hangers
- Unsealed seams and fittings throughout
- Supply air boot condensation damage
- Moisture and mold damage to duct insulation and attic floor.

Insulated Ductwork - Condensation and Contributing Conditions



Observed Issues:

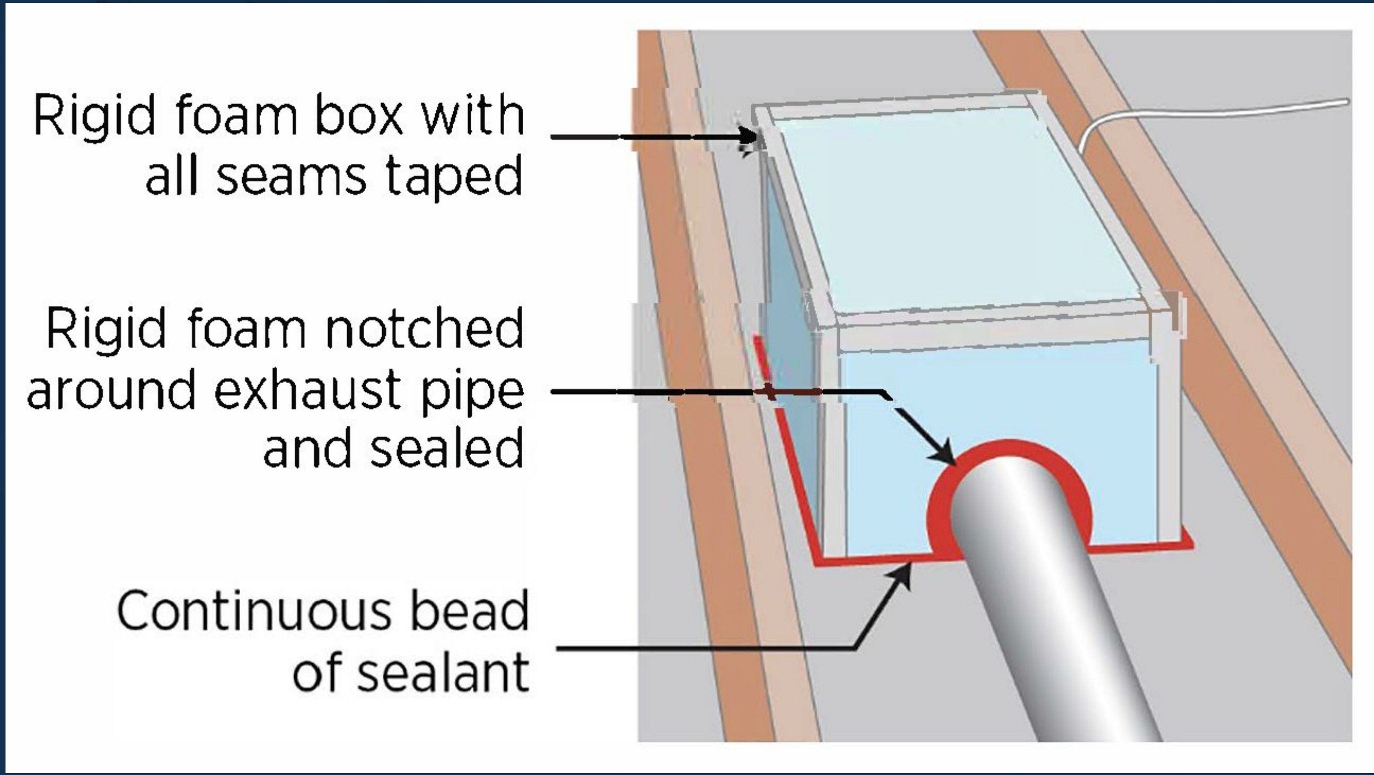
- Condensation drip pattern (left)
- Incorrect insulation termination (left)
- Correct installation (right)

Exhaust Fan Penetration - Gap Clearance and Connectivity to Buffered Unconditioned Space

Observed Issues:

- Steel ruler test showing gap clearance to buffered unconditioned space.
- Exhaust fan not set correctly on GB ceiling.

Exhaust Fan - Resulting Damage and Recommended Installation Practices



Observed Issues:

- Suspect mold growth at ceiling adjacent to fan housing
- Insulated exhaust fan housing recommended by Building America Solutions Center and Pacific Northwest National Laboratory (PNNL). Not shown building insulation adjacent to and above housing.

Supply Air Register Boot and Gypsum Board Ceiling Damage

Observed Issues:

- Suspect mold growth at ceiling adjacent to supply air boot
- Corrosion and possible mold growth on supply air boot.

Mechanical Room Plenum Smoke Visualization

Observed Issues:

- Gaps and unplanned pathways for return air.

Mechanical Room Plenum Smoke Visualization

Observed Issues:

- Smoke visualization testing showing air infiltration up through the condensate drain at the indirect drain location

Case Study 1: Findings Summary Table

Issue	Contributing Condition	Scope	What the Evidence Showed
Condensation at insulated ductwork	Installation-sensitive insulation, warm-humid unconditioned space	Design	Insulation type not suited to field conditions in CZ 2A
Condensation at insulated ductwork	Not installed per manufacturer instructions	Installation	Corrosion, oxidation, condensate drip patterns
Infiltration at supply air boot penetrations	Boot frames not sealed to ceiling	Installation	Gap ruler confirmed; condensation migration at ceiling
Infiltration at exhaust fan penetrations	Fan housings not air-sealed; gravity backdraft damper inadequate	**Design/Installation**	Mold at housing and GWB; reverse airflow confirmed

Case Study 1: Findings Summary Table

Issue	Contributing Condition	Scope	What the Evidence Showed
Infiltration - Return air plenum pressure	Discontinuous air barrier at mechanical room plenum	**Design/Installation**	Smoke testing confirmed airflow; up to -19.6 Pa measured
Infiltration - uncompensated exhaust loads	No dedicated outdoor air; five flues, five exhaust ducts, 400 CFM dryer, elevator	Design	Building depressurized under all conditions; infiltration only makeup air source
Condensate drainage	Absent traps on negative-pressure AHUs	**Design/Installation**	Air infiltration through open drain confirmed; pan overflow; inoperable safety switch

Case Study 1: Operational Pressure Measurements

Location	Room Pressure (Pa)	Reference	Remarks
Mechanical Room	-1.6	Third Floor Corridor	3rd Floor AHU ON, Doors Closed
Mechanical Room	-5.2	Third Floor Corridor	2nd Floor (south) and 3rd Floor AHUs ON, Doors Closed
Mechanical Room	-4.7	Third Floor Corridor	2nd Floor (south), 2nd Floor (tower), and 3rd Floor AHUs ON, Doors Closed
Mechanical Room	-19.6	Third Floor Corridor	1st Floor (main), 2nd Floor (south), 2nd Floor (tower), and 3rd Floor AHUs ON, Doors Closed

"What Closing a Door Does"

Case Study 1: OPM - Key Takeaways

"5 Pa conducive to moisture damage"

"This home operated at approximately 5 Pa under certain operational conditions"

-19.6 Pa

"All AHUs Operating, Doors Closed

"The opening that allowed this pressure to build was not in the field of the wall."

Case Study #1 - Summary

Uncontrolled Airflow from mechanical effects and wind

Pathways for infiltration unbalanced airflow are through planned openings

Design, Installation and a combination of both are contributing to the damage in this custom home

Operational conditions are having a huge influence on HVAC pressure and airflows

Multiple Issues are contributing to the conditions that exist.

Limited Service Hotel

Case Study 2 - Climate Zone 3A

Project Context

Location Details:

Warm and Humid environment within Climate Zone 3A.

Project Focus:

Causes, mechanisms, and pathways contributing to moisture damage, including recurring damage and mold growth

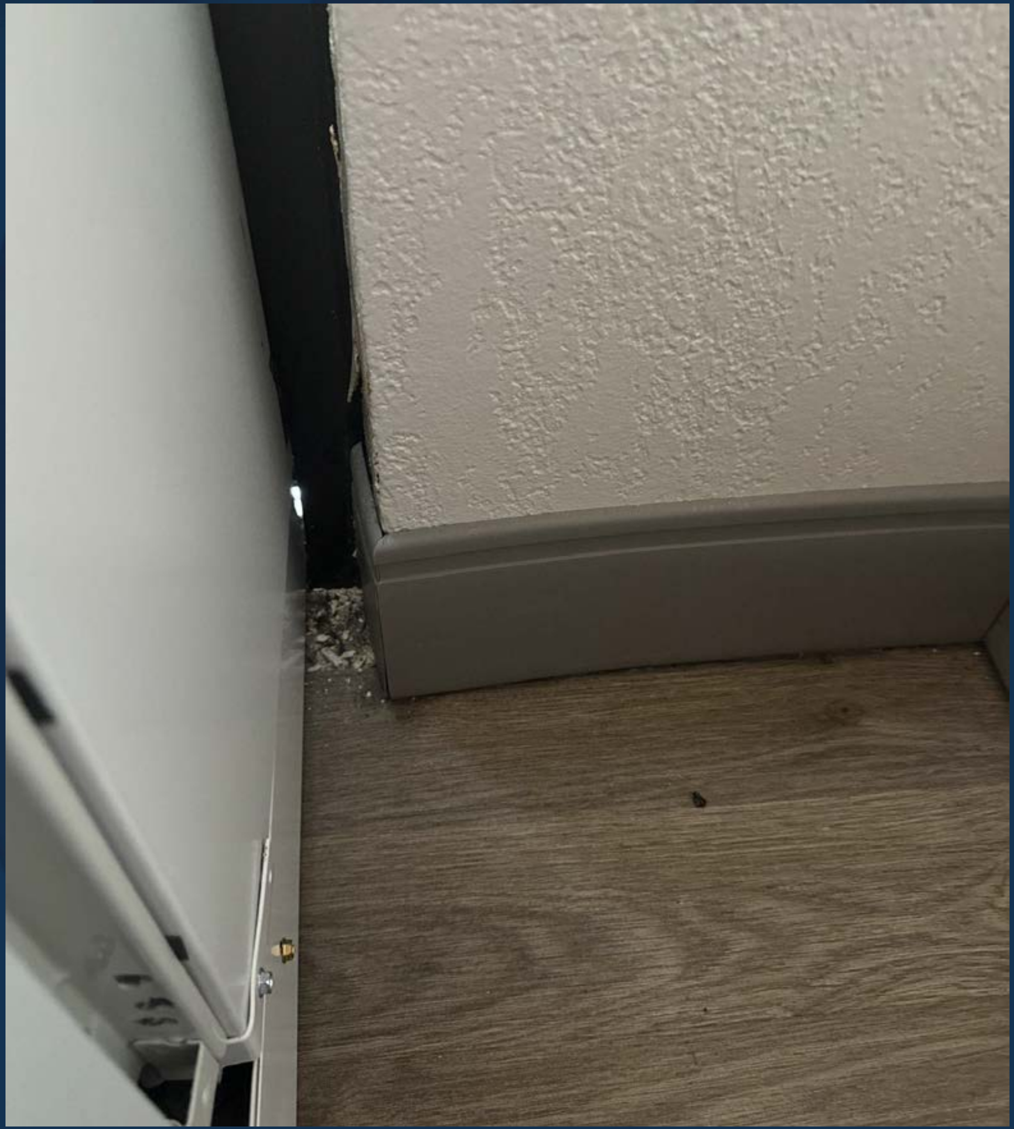
Limited Service Hotel

Roof View of Exhaust Fan Yard

Key Takeaway:

- Mechanical openings, not the envelope, created infiltration paths.

Opening in PTAC Wall Louver - Infiltration Pathway into Guestroom



Observed Issues:

- Unit 111. Note: Opening in PTAC wall louver for air infiltration into the room.

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PTAC Standing Water and Corrosion

Observed Issues:

- Standing water and corrosion in PTAC sleeve (right)
- Corrosion staining at PTAC casing end cap (right)

Unsealed Openings Driving Uncontrolled Airflow at Exhaust Fan Curb

Observed Issues:

- Exhaust shaft - Openings at duct corners extracting air from wall cavities

Unsealed Openings Driving Uncontrolled Airflow in Exhaust Duct Risers

Observed Issues:

- Air gap at cable penetration; absent sub-duct (left)
- Multiple unsealed shaft penetrations

Fifth Floor: Chronic High Humidity Conditions

Observed Issues:

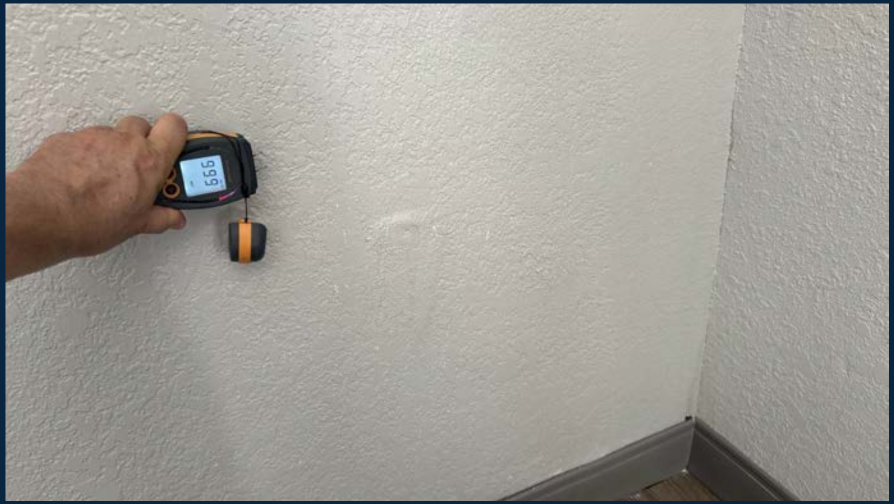
- Corroded fire suppression piping above 5th floor ceiling (top left)
- Corroded Ceiling Grid from Chronic High Humidity (bottom right)

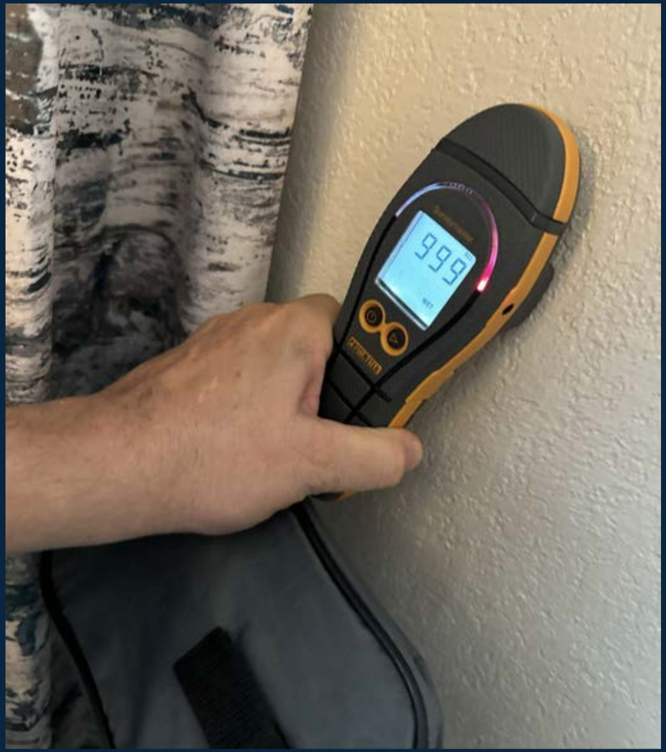
Second Floor: Temporary Supplemental Dehumidification

Observed Issues:

- One of two active dehumidifiers shown in a second floor room to maintain acceptable conditions

Select Moisture Measurements of Wet Conditions





Observed Issues:

- Room 519 - Moisture measurements of demising wall near PTAC - Wet GWB
- Room 213 - Moisture measurements indicating wet GWB

Case Study 2: Findings Summary Table

Issue	Contributing Condition	Scope	What the Evidence Showed
Infiltration - PTAC wall penetration	~4.5 SF planned envelope opening per unit; chassis/sleeve compatibility not confirmed	**Design/ Installation**	Negative pressures -36.7 to -40.7 Pa measured in guest rooms; moisture damage at PTAC walls
Infiltration - continuous exhaust system	Exhaust rates 1.6x code; no makeup air; sheet metal not flashed at exhaust curbs	**Design/ Installation**	Air extracted from wall cavities and unintended locations; unsealed penetrations at exhaust shafts
Infiltration - elevator hoistway	Louvered vents open under normal operation; no normally-closed smoke dampers	Design	Warm-humid air distributed vertically through building; corrosion at 5th floor ceiling components
Inadequate dehumidification	Continuous exhaust overwhelms PTAC dehumidification capacity	Design	Indoor dewpoints 55°F–67°F exceeding ASHRAE 55°F maximum; wet GWB at demising walls

Case Study 2: Findings Summary Table

Issue	Contributing Condition	Scope	What the Evidence Showed
Condensate management - PTAC	Condensate slinger unable to manage pan accumulation under continuous exhaust conditions	**Design/ Installation**	Standing water in PTAC sleeve base; pan overflow into wall sleeve; corrosion at metal framing
Unbalanced airflow - elevator lobby	Supply air does not re-circulate without ice machine room door open; unbalanced duct design	Design	Lobby at +8.3 Pa relative to ice machine room; dehumidifier required continuously
No dedicated outdoor air	No makeup air provision in original design	Design	First floor lobby at -9.7 Pa relative to outdoors; infiltration only makeup air source throughout building

Case Study 2: Operational Pressure Measurements

Location	Room Pressure (Pa)	Reference	Remarks
5th floor elevator lobby	-1.6	Ice machine room	—
5th floor corridor	0.0 to 0.5	Above corridor ceiling	—
Room 519	-36.7	Outdoors	PTAC ON
Room 519	-40.7	Outdoors	PTAC ON, EF ON
Room 219	-0.2	Corridor	PTAC ON, EF ON
Room 213	5.2 (wind-driven)	Corridor	PTAC OFF, EF OFF
1st floor lobby (back door)	-9.7	Outdoors	—

Case Study 2 - Summary

Uncontrolled Airflow exists from mechanical effects and wind

Pathways for infiltration are primarily through planned openings

Design and a combination of design and installation issues are contributing to the damage in this hotel

Multi-Family

Case Study 3 - Climate Zone 2A

Project Context

Location Details:

Hot and Humid environment within Climate Zone 2A.

Project Focus:

Causes, mechanisms, and pathways contributing to moisture damage, including recurring malodor and mold growth

Duct Leakage Evidence

Observed Issues:

- Backside ceiling gap between supply discharge duct and wall. Unplanned airflow pathway (left)
- Attic side of supply discharge duct/plenum. Note: Condensation, SMG and air leakage site (right)

Attic Conditions - Air Leakage and Mold

Observed Issues:

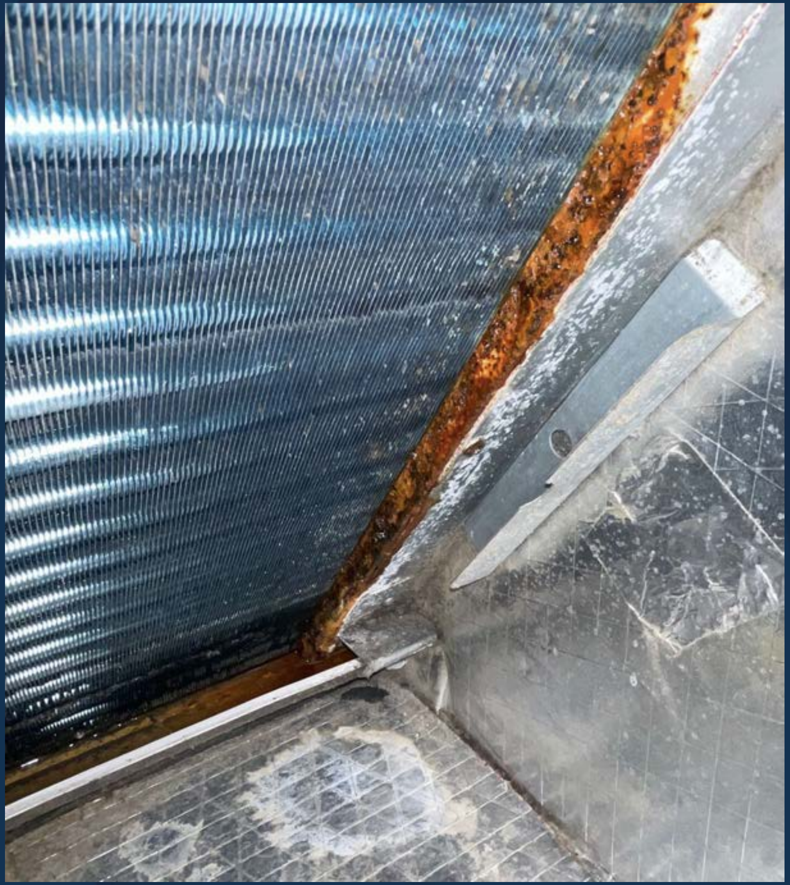
- SMG, ghosting and air leakage (left)
- Condensation and SMG

Ceiling Plane - Air Leakage and Mold

Observed Issues:

- Air leakage, condensation and SMG (left)
- Evidence of condensation, corrosion and SMG (right)

AHU and Air Distribution Conditions



Observed Issues:

- Corrosion and SMG on cooling coil (left)
- SMG on fan wiring

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AHU and Air Distribution Conditions

Observed Issues:

- SMG inside supply discharge duct at radiation damper (left)
- SMG on dirt on radiation shield and flex duct (right)

Case Study 3 : Findings Summary Table

Issue	Contributing Condition	Scope	What the Evidence Showed
Duct leakage - supply system	Unsealed flex-to-plenum and flex-to-boot connections	**Design/ Installation**	144 CFM@25Pa total. More than 4× required by code; supply leakage to outdoors 124 CFM@25Pa
Infiltration - supply duct as driver	Excessive supply leakage depressurizes living unit	**Design/ Installation**	105 CFM of unconditioned outdoor air drawn into a 740 SF unit - ~20% of supply airflow from infiltration
Vented attic - non-airtight ceiling barrier	Gaps at AC plenum closet ceiling, plumbing penetrations, and condensate drain wall penetration	**Design/ Installation**	Airflow confirmed attic-to-conditioned-space; AHU closet at −3.3 Pa wrt living unit - pulling attic air into return stream
Thermal bridging - supply registers	Cold registers penetrate attic floor without insulation at boot support frame	**Design/ Installation**	Condensation at register boots; mold on supply grilles and ceiling

Case Study 3: Findings Summary Table

Issue	Contributing Condition	Scope	What the Evidence Showed
Condensation - condensate drain line	Uninsulated drain line through exterior garage wall; penetration unsealed	**Design/ Installation**	Condensation on drain pipe exterior; open penetration serves as direct garage-to-conditioned-space moisture pathway
Water intrusion - grade drainage	Roof gutter, stair landing, and AC condensate converge at foundation with no diversion	Design	Moisture staining at foundation; garage floor staining; wall insulation wet to the touch; mold at baseboards
Building envelope tightness	Top plates, sill plates, and service penetrations not sealed	Installation	Blower door: 6.29 ACH@50Pa — exceeds 2014 Florida code maximum of 6.0 ACH; wall cavities negative under AC operation

Case Study 3: Operational Pressure Measurements (Table 1)

Location	Room Pressure (Pa)	Reference	Remarks
Unit K201	0.60	Outdoors	AC OFF, Exhaust Fan OFF
Unit K201	-2.5	Outdoors	AC ON, Exhaust Fan OFF
Unit K201	-1.9	Garage	AC ON, Exhaust Fan OFF
AC Closet	-3.4	Unit K201	AC ON, Exhaust Fan OFF
Unit K201	-2.0	Wall cavity (exterior wall)	AC ON, Exhaust Fan OFF
Unit K201, Bedroom	-2.2	Wall Cavity	AC ON, Exhaust Fan OFF

Key Takeaways?

Case Study 3 - Summary

Uncontrolled airflow is occurring due to mechanical effects; estimated operational infiltration is approximately 105 CFM.

Supply and return duct leakage are present. Supply leakage exceeds return leakage, contributing to negative space pressure, while return leakage contributes to inadequate dehumidification.

Primary infiltration pathways are through planned openings.

HVAC design and installation are contributing to these issues and to the underlying causes of malodor and damage.

The Envelope and HVAC are Not Independent

What This Means for Air Barrier Design and Specification

- Air barrier continuity is critical but not sufficient; enclosure and HVAC must function as an integrated system.
- Require operational pressure measurements (OPMs) during commissioning, not just whole-building air leakage at 75 Pa.
- Detail ceiling plane air barrier continuity at all mechanical penetrations (register boots, exhaust fans, condensate drains).
- Coordinate HVAC design to ensure adequate makeup air for exhaust loads, recognize wind loads may not be fully offset, and maintain accurate duct distribution, especially in multifamily and hospitality.

Conclusions

- The pressures that cause catastrophic moisture damage are not the pressures we test at.
- Avoid the first inclination to tighten the building envelope, instead, ask, how are the HVAC systems contributing to the extent of damage.
- One issue alone does not cause a catastrophic failure. According to ASHRAE, it is the compounding of conditions that drives the extent of damage.

Questions?

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Thank you

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