

Kohta Ueno

Tools of the Trade for
Building Diagnostics



BUILDINGENERGY
BOSTON

MARCH 14-15, 2019 • WESTIN BOSTON WATERFRONT • NESEA.ORG/BE19
Conference + Trade Show of the Northeast Sustainable Energy Association [NESEA]

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Course
Description

Description: How do you go about diagnosing a sick, leaky, dripping, humid, dry, or uncomfortable building? Join this speaker for an overview of the tools that he commonly uses in his diagnostic work on building enclosures and mechanical systems. Everything from the air side (blower doors, airflow meters, flow sensors) to the moisture side (spray testing, moisture meters, hygrometers) to the heat side (infrared cameras, temperature meters)-- instruments that measure things that are not easily visualized. We will use multiple case studies to demonstrate how these measurements provided actionable results in solving problems.

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Learning Objectives

At the end of the this course, participants will be able to answer:

1. Explain some of the pitfalls of using infrared thermography in diagnostics.
2. Explain some of the basic techniques used for diagnosing residential-scale air handler systems.
3. Explain how a blower door is useful for more than obtaining a CFM50 number.
4. Explain how water spray testing may or may not be useful, or the right tool to answer where the leak is coming from.

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Introduction

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Overview

- Kohta = Geeky NESEA talks on building moisture physics
- Day job = exploring the bowels of messed-up buildings
 - Freezer warehouse icicles
 - Rich guy's house high RH
 - Airport control tower leaking water
- Forensic work kit of tools—"beyond eyeballs"
 - What works for me; might work for you
 - Relation to NESEA mission?
- Indebted to practitioners who I have learned from
 - ^{almost} No graphs!



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Apologies to Samin...



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Apologies to Samin...



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Housekeeping

- Slides will be available on website (<https://www.buildingscience.com/past-events>)
- Tools and resources: list of links at end of presentation
- Questions—during plus reserved Q&A time at end

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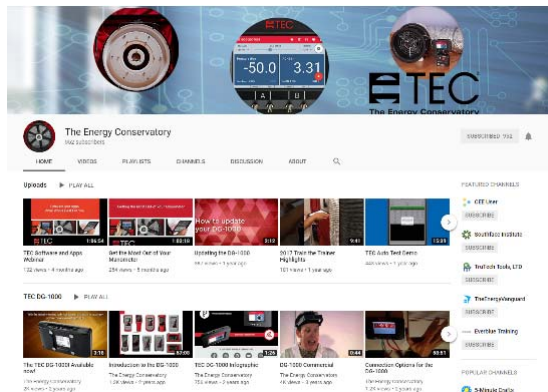
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Air

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Not Blower Door/Air Leakage 101

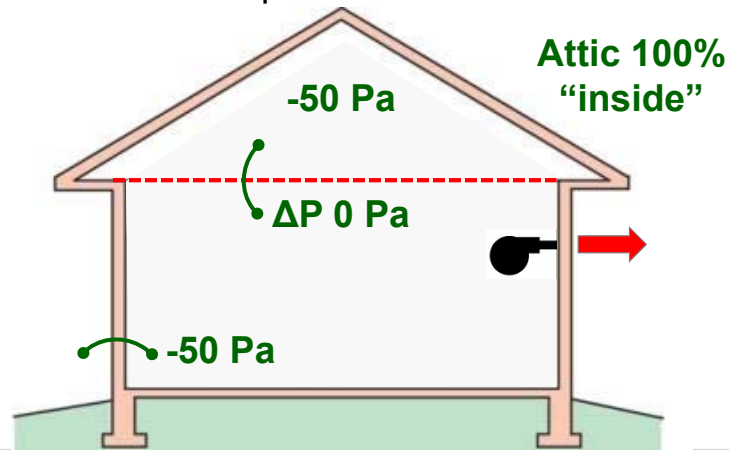


- Lots of resources—e.g., Energy Conservatory website/YouTube
- Tips, tricks, uncommon applications

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Pressure Difference (ΔP) to Spaces

- Blower door running/building depressurized
- How “connected” space is to outdoors vs. building



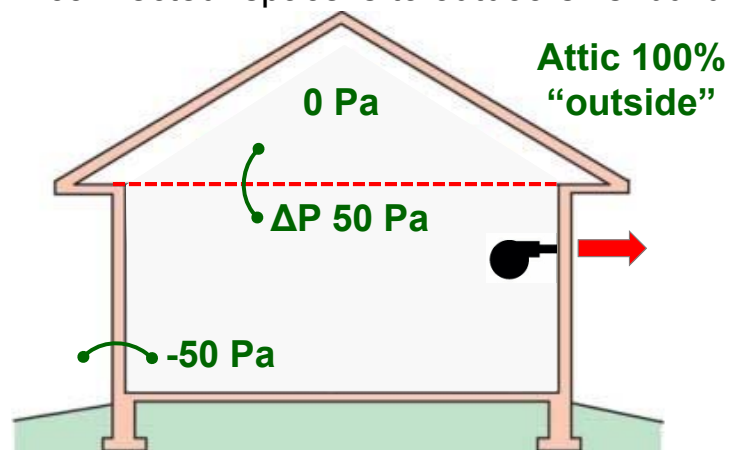
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Pressure Difference (ΔP) to Spaces

- Blower door running/building depressurized
- How “connected” space is to outdoors vs. building



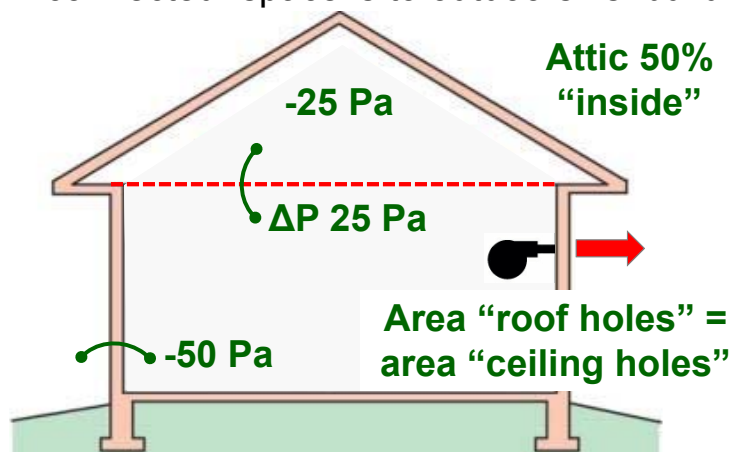
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Pressure Difference (ΔP) to Spaces

- Blower door running/building depressurized
- How “connected” space is to outdoors vs. building



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Pressure Difference (ΔP) to Spaces



- Fireplaces taped off, ΔP measured—dampers OK?
- All significantly “outside” (ΔP 25-35 Pa)
- More rigorous “add a hole method”

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Indoor-Outdoor Pressure Differences (ΔP)



- Mechanical pressurization/depressurization
- Demonstrate/measure stack effect
 - Tall buildings, cold weather = big stack effect

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Pressure Logging (TECLOG)



- Manometer + computer = pressure log file
- Useful for turning mechanicals on/off
- Can network together many manometers, distributed around building

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Duct Blaster for Airtightness Testing



- Multifamily units, small houses, very tight houses
- “Relieve” pressure hallway-to-exterior in multifamily

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Case Study: Pool Roof-Wall Air Barrier

- Academic pool building stripped, re-insulated, reclad
- Climate Zone 6A
- Efflorescence staining in first winter



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Case Study: Pool Roof-Wall Air Barrier

- “Perfect wall”



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Case Study: Pool Roof-Wall Air Barrier

- Excellent roof (air-vapor barrier below)



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Case Study: Pool Roof-Wall Air Barrier



- Pressurize pool space with blower door

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Case Study: Pool Roof-Wall Air Barrier



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Airflow Meter (Hot-Wire Anemometer)



- In Duct Hot-wire Anemometer
- Measures air velocity (feet per minute/FPM) & T
- Better than toilet paper for demonstrating airflow!
- Extended probe—more reach

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HVAC Airflow Measurement



LowFlo Balometer
10-500 CFM



Exhaust Flow Meter
Exhausts, 10-124 CFM



Toilet Paper
Good/Bad Flow

- Flow hood accuracy: many common options have poor results @ residential flows, off-center...

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Heat

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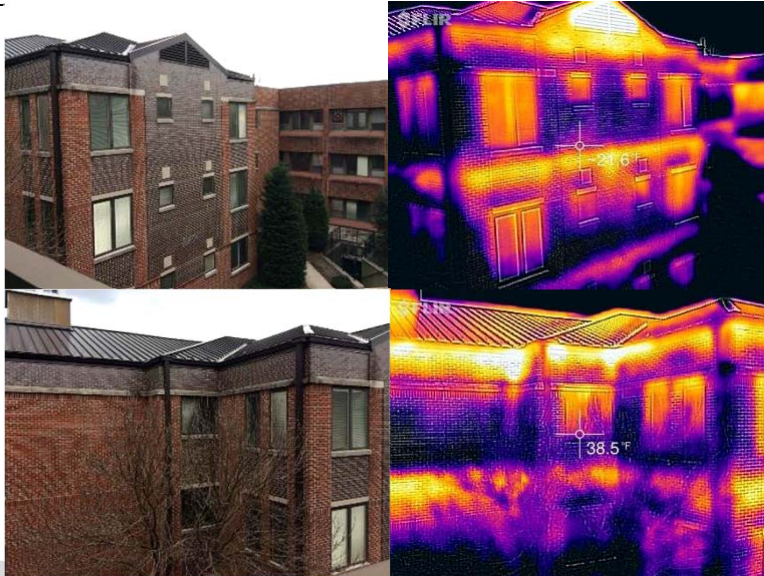
Infrared Cameras

- Not infrared thermography 101
- “Thermal anomalies”—hot and cold spots; must be interpreted
- Air leaks, water leaks, heat sources, thermal bridges, solar gain...



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Air Leakage Example

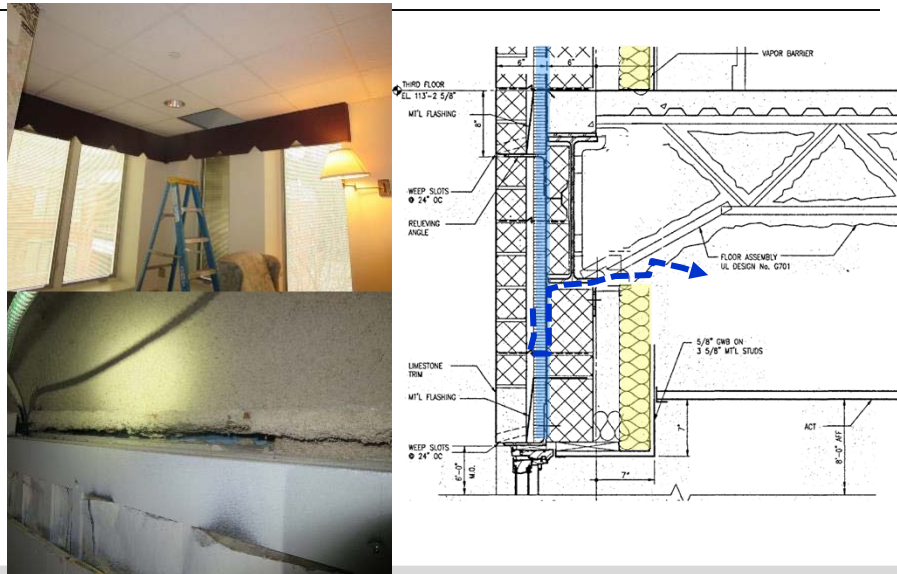


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Air Leakage Example



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Surface Water Example



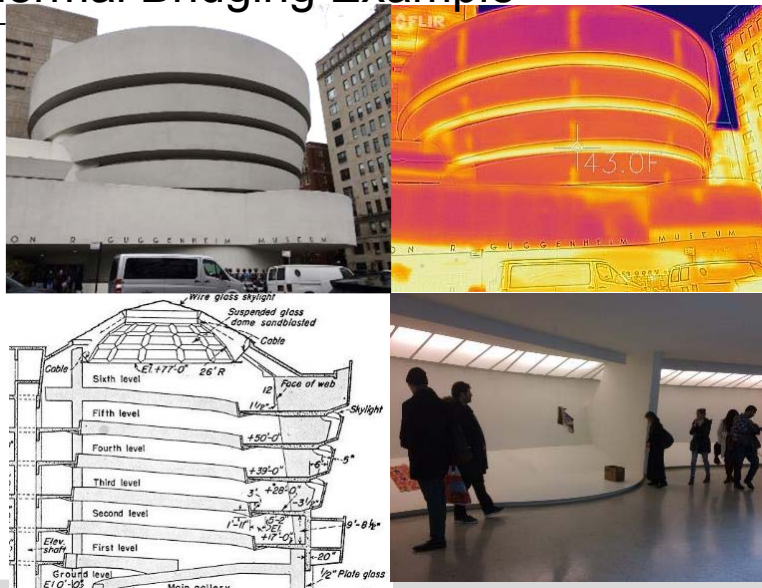
- Tricky part—catching building after the “right” amount of rainfall
- Outdoor temperature and sun too (T rising/falling)

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Thermal Bridging Example



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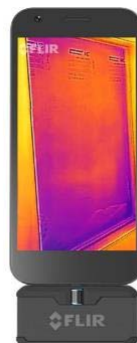
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Infrared Cameras



FLIR b40
 ~\$5000 when new (~2008)
 Pelican case w. charger
 240 x 240 resolution



FLIR ONE Pro
 ~\$400
 Fits in pocket, phone add-on
 1440 x 1080 resolution

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Infrared Camera Warnings

- Software sometimes hangs
- Battery drain
 - Cold temperatures outdoors
- Be careful of the connector!
- Accuracy of temperatures not great
- Lots of brands/products out there (limited experience)
- IR camera shows surface temperatures: reflections, shiny surface emissivity



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Pair Visual and Infrared Images



- Current IR cameras → edge detection from visual
- Visual image always adds information

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Occasional Surprises



- Assumes $\epsilon_{\text{cat}}=0.9$

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Occasional Surprises



- Assumes $\epsilon_{cat}=0.9$

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Air Temperature/RH Meters




Dual In Duct Psychrometer
~\$250

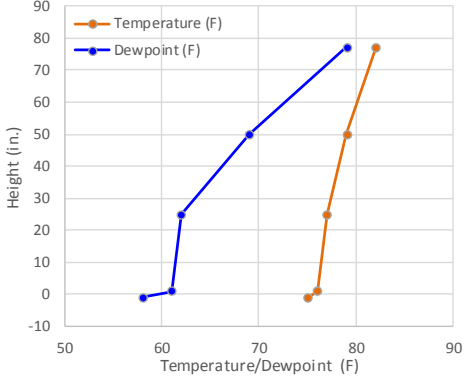
Temperature/
Humidity Pen ~\$35

- Temperature, relative humidity (RH), dewpoint
- Dewpoint useful to compare air moisture levels

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T/RH Meter Unvented Attic Stratification





Height (in.)	Temperature (F)	Dewpoint (F)
0	75	58
10	75	60
25	75	65
50	75	70
75	75	75
80	82	78

- Temperature and dewpoint stratification directly measured
- 90%+ RH near ridge
- System is not in equilibrium

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Air + Heat (Enclosure Leakage)

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Pressurization/Depressurization + IR

Pressurization
Air leaks can be visualized on exterior of building
Often overwhelmed by exterior conditions

Depressurization
Air leaks can be visualized on interior of building

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Air Leakage at Doors/Windows/Outlets

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Tongue & Groove Roof/Ceiling Overhangs

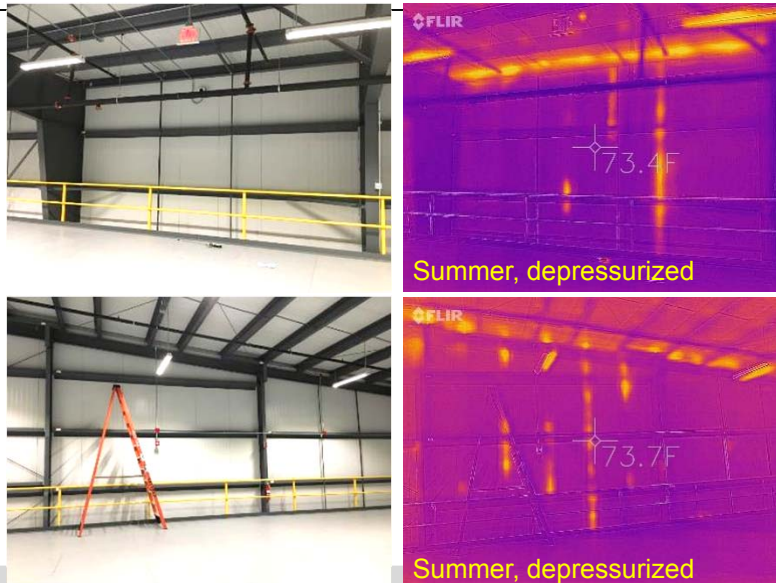


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Insulated Metal Panel Art Storage



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Air Leakage Behind Interior Finishes

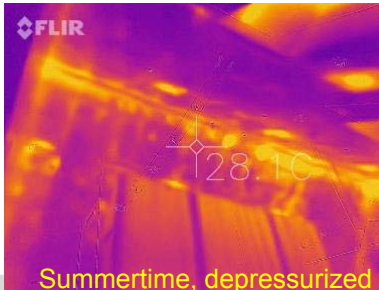
Vented attic above



Summertime, depressurized



Cathedral Roof/ceiling



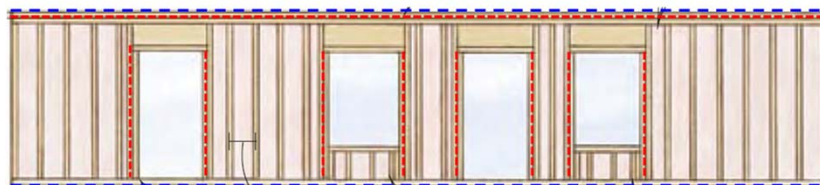
Summertime, depressurized

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Spray Foam as an Air Barrier



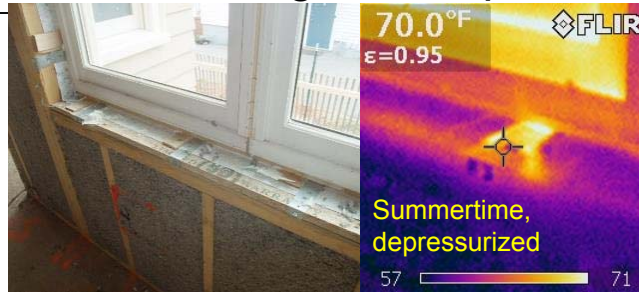
- Spray foam doesn't air seal where it isn't there!
- Wood-to-wood connections

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Window Air Sealing with Clips



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Air + Heat (HVAC Measurements)

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Air Handler Temperature/RH



- Diagnosing humidity control problems
- “Split” (return-supply ΔT) indicates performance
- 18-20 F “split” means good dehumidification
 - Oversized ACs common: low split but still cools building

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Air Handler Temperature/RH

System	ΔT	ΔDP	ΔT	ΔDP
1	18.0° F	4.0° F	██████████	███
2	18.0° F	8.0° F	██████████	██████
3	7.0° F	2.0° F	██	█
4				
5				
6	11.0° F	3.0° F	██████	█
7	12.0° F	2.0° F	██████	█
8	11.0° F	1.0° F	██████	

- 18-20 F “split” means good dehumidification
- Also measure supply vs. return dewpoint
 - Direct measurement of moisture removal
- Suspects: bad refrigerant charge, excess airflow

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Air Handler Temperature/RH (PTAC)



Unit/Condition	ΔT	ΔDP	ΔT	ΔDP
C2-Fan On	2.0° F	-2.0° F	■	
C2-Cooling On	17.0° F	13.0° F	■■■■■	■■■■■
D2-Fan On	5.0° F	-2.0° F	■	
D2-Cooling On	20.0° F	15.0° F	■■■■■	■■■■■

- PTAC cooling **ON**/fan on: $\Delta DP = 13-15F$
- PTAC cooling **OFF**/fan on: $\Delta DP = -2 F$
 - PTAC is adding moisture to the room!
- Continuous PTAC fan = terrible dehumidification

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Air Handler Static Pressure, Airflow



- Supply to return $\Delta P =$ “external static pressure”
 - Typical target 0.5 IWC/125 Pa or less
- Flow plate to measure airflow (in filter slot)
 - Airflow “choked” or not by bad duct design?

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Water

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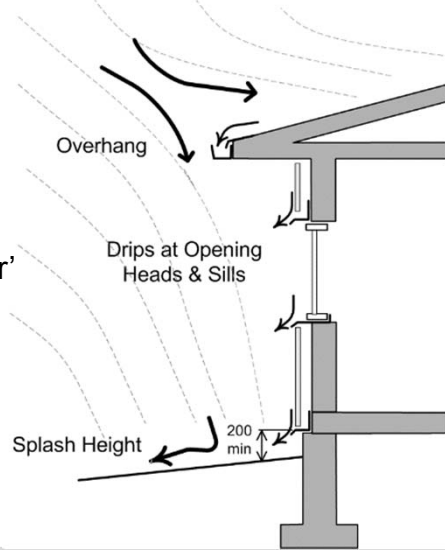
Water and Buildings

- Most common reason for building problems
- Rain penetration first
- Air leakage
- Vapor rarest problems

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The Three “D”s of Rain Control

- Deflection
- Drainage, storage, exclusion
 - Drainage = rainscreens
 - Storage = mass
 - Exclusion = ‘perfect barrier’
- Drying
- Missing emphasis on deflection—keep the rain off the building!



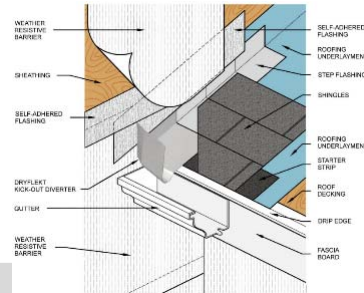
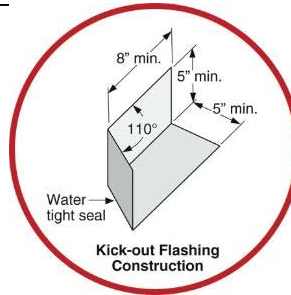
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Deflection/Surface Water Loading



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Kickout Flashings

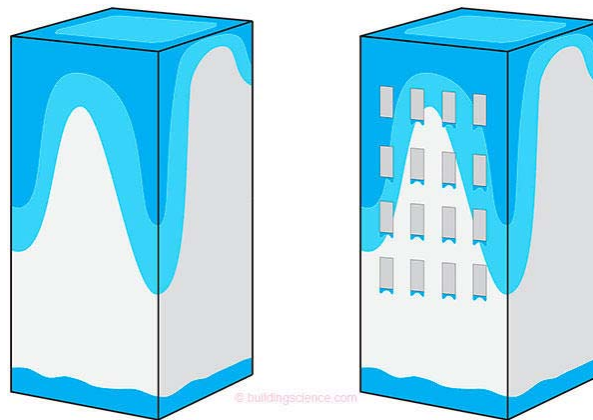


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Wetting Patterns



- “Where the building touches the ground and touches the sky”

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Very Simple Water Testing



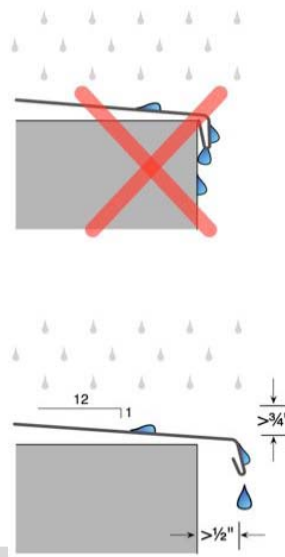
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Simple Testing of Drip Edges



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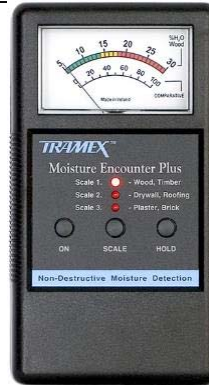
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Moisture Meters



Delmhorst BD10
Pin-based MC meter
Wood products (typical)
Electrical resistance



Tramex Moisture Encounter
Capacitance-based MC meter
Wood, plaster, concrete

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Wood Moisture Contents

- Below 20% MC=safe
- 25-30% MC mold range
 - But seasonally survivable!
- 28%+ MC decay fungi
- Really wet wood is obvious (feels wet)
- Don't forget about temperature when wet (mold doesn't grow in the freezer)



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Capacitance Meter Measurements

- Wood MCs 0-30%
- Non-wood shown on 0-100 relative scale
- Concrete can stay wet... but what does it touch?
- Patterns of wetting
- Watch out for metal (e.g., drywall bead)



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Case Study: Multi-Use Building RI

- Sleepers and Advantech on slab on grade
- Rubber-backed carpet tile, OK over basement



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Case Study: Multi-Use Building RI

- Damage pattern matches seams of carpet tile
- High wood MCs: 18-25% typical



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Case Study: Multi-Use Building RI

- Advantech damaged on top; bottom wetter
 - Tramex and Delmhorst measurements



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Case Study: Cupping Floor Maine

- Modified ASTM F2170 test (slab RH in drilled hole)
- Lower parts of slab 95%+ RH
- 4 months + of drying



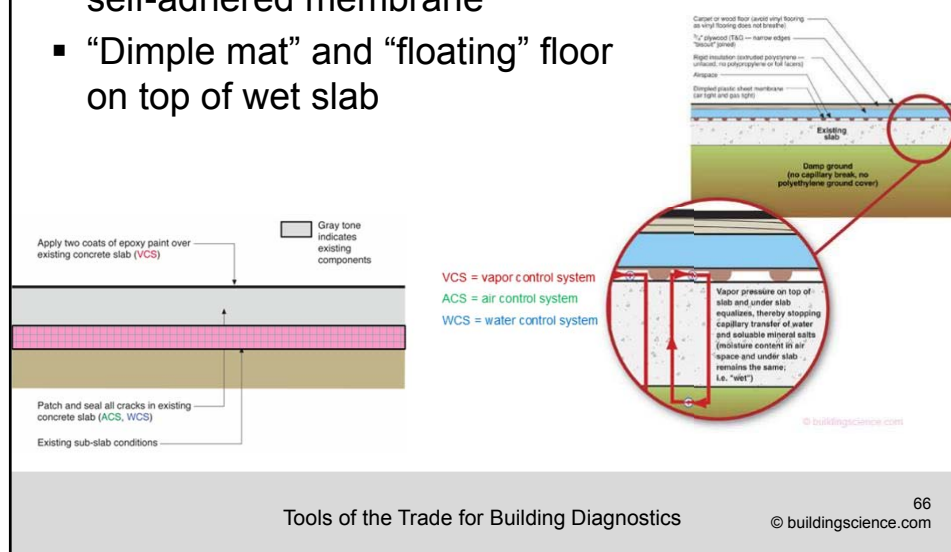
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Fixing Wet Slabs

- Build back with epoxy coating on slab, or self-adhered membrane
- “Dimple mat” and “floating” floor on top of wet slab



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Water + Air (Window Testing)

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Complicated Water Testing



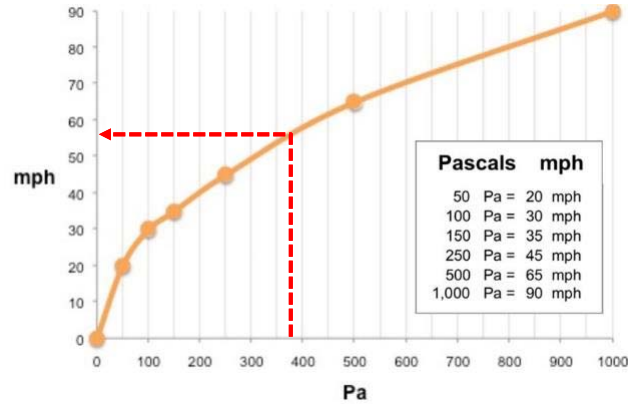
- AAMA 502/ASTM E1105 or similar
 - Depressurize window (vs. rating), spray rack, timed test
- Specialized contractors
- Typical for new construction QC testing

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Wind Speed vs. Stagnation Pressure



- 8 PSF window test = 383 Pa = 55 mph
- Rain + continuous 55 mph = hurricane
- Leaky buildings often leak without ΔP

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Simple Water Testing (Diagnostics)



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Simple Water Testing (Diagnostics)



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Simple Water Testing (Diagnostics)



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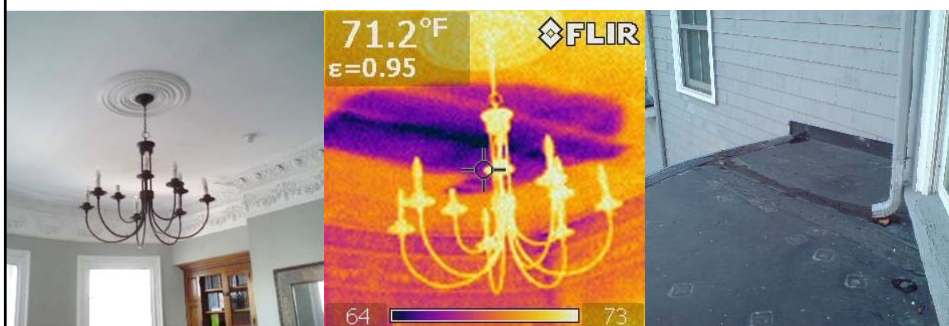
Water + Heat (Finding Water Leaks)

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Water Leakage Infrared Signature



- Water leaks = cooler surface due to water temperature, evaporation

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Balcony Water Flow Pathway



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Balcony Water Flow Pathway



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Organization

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Boring Part of the Presentation

- Photographs/
photodocumentation
- Disassembly & Other
Tools
- My use case: flying to
sites
- Heavy equipment
(blower doors) FedEx
Ground to site



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Investigation Photos 101



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Boroscope Cameras?



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Cut a Hole and Stick a Camera In It



Looking upward and back towards house (wall sheathing)

Looking upward and towards curved roof sheathing

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Selfie Stick (!?!)



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Carrying Tools



- Work in confined spaces
- Efficiency (carpenter up and down ladder)

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Tool Organization



- Camera bag
- Don't forget batteries!
- Not dead batteries

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Tool Organization



- Headlamp
- Multi-bit screwdriver
- Electrical tester
- Disassembly tools



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Safety/PPE/Emergency



- “Don’t die.”
- PPE/fall arrest gear—beyond scope today
- Company emergency contact list

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Questions?

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Equipment Resources: Air/Heat

- Energy Conservatory (Blower Doors, Duct Blasters, and More)
<https://energyconservatory.com/>
- Energy Conservatory TECLOG 4 Software
<https://energyconservatory.com/products/product/teclog/?categories=6>
- Energy Conservatory YouTube Channel
<https://www.youtube.com/user/energyconservatory>
- Energy Conservatory Exhaust Fan Flow Meter
<https://energyconservatory.com/products/product/exhaustfanmeter/?categories=5>
- Energy Conservatory TrueFlow® Air Handler Flow Meter
<https://energyconservatory.com/products/product/trueflow/?categories=5>
- Fieldpiece Instruments STA2 - In Duct Hot-wire Anemometer
<https://www.fieldpiece.com/products/detail/sta2-in-duct-hot-wire-anemometer/anemometers/>
- Fieldpiece Instruments SDP2 - Dual In-Duct Psychrometer
<https://www.fieldpiece.com/products/detail/sdp2-dual-in-duct-psychrometer/psychrometers/>
- Extech 44550: Pocket Humidity/Temperature Pen
<http://www.extech.com/display/?id=14261>
- Alnor® LoFlo® Capture Hood 6200D
<https://www.tsi.com/alnor-loflo-balometer-capture-hood-6200d/>

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Equipment Resources: Water/Heat

- FLIR ONE Pro
<https://www.flir.com/products/flir-one-pro/>
- Delmhorst Instrument BD-10 (pin/resistance MC meter)
<https://www.delmhorst.com/moisture-meters/bd-10>
- Tramex MEP Moisture Encounter Plus (capacitance MC meter)
<https://www.tramexmeters.eu/mep-moisture-encounter>
- Cobalt Chloride Test Papers (1 vial of 100 strips)
<https://www.amazon.com/Cobalt-Chloride-Test-Papers-strips/dp/B01M30VDLK/>
- Rbenxia Tattoo Wash Cleaning Plastic Green Soap Holder Squeeze Bottle
<https://www.amazon.com/gp/product/B00CALRRYO/>
- AmazonBasics Large DSLR Gadget Bag (Gray interior)
<https://www.amazon.com/gp/product/B00CDS9HTM>
- Conterra Tool Chest Radio Chest Harness
<https://www.conterra-inc.com/products/tool-chest-radio-chest-harness>

Document Resources: Case Studies

- Case Study: Pool and Recreation Facility
<https://www.buildingscience.com/project/pool-and-recreation-facility>
- Case Study: Mixed-Use Building
<https://www.buildingscience.com/project/mixed-use-building>
- Case Study: Humidity Control Investigation
<https://www.buildingscience.com/project/humidity-control-investigation>
- Case Study: Window Leakage
<https://www.buildingscience.com/project/window-leakage>
- Building Science Insight 003: Concrete Floor Problems
<https://buildingscience.com/documents/insights/bsi-003-concrete-floor-problems>
- Building Science Insight 057: Hockey Pucks and Hydrostatic Pressure
<https://www.buildingscience.com/documents/insights/bsi-057-hockey-pucks-and-hydrostatic-pressure>
- Building Science Experts' Session | DAY 2: November 8, 2018 | Westford, MA:
Pools and Special Use Buildings
https://www.buildingscience.com/sites/default/files/pools_special_use.pdf