Kohta Ueno

Failures and Best Practices in Medical/Educational Buildings

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MEDED FACILITIES

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Course Description

Description: Medical and educational buildings have exacting requirements for interior conditions, and are often operated at conditions that increase moisture-related failure risks. These practitioners will share lessons learned from a variety of field investigations of building failures, with recommendations on how they could have avoided those problems. Investigated problems included pressure fields pulling contaminants out of unknown locations, inward vapor drives, and air leakage-based condensation in cold climates.

Learning Objectives

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

1. Understand how unintentional pressurization or depressurization can raise moisture-related failure risks
2. Understand some of the challenges associated with a pressurized and humidified space in a cold climate
3. Gain a greater understanding of the critical role of air barriers
4. Understand how to address inward vapor drive with reservoir claddings

Overview of Med/Ed Challenges

Medical/Educational Challenges

- Medical
  - Interior humidification
  - Positive pressurization
  - Stringent interior conditions/IAQ requirements
- Educational
  - "Burst" occupancy (intermittent high occupant load)
  - Ventilation requirements high but intermittent
  - IAQ requirements
- Presentation Approach
  - Failure case studies
  - Building science background
  - Recommended best practices

Medical/Educational Failures

- Some failures specific to medical use
  - Covered here
- Many others non-specific to medical buildings
- Water leaks dominate these failures
- Flashings
- Air leakage and comfort

Air Flow and Air Leakage

Airflow Control: Why?

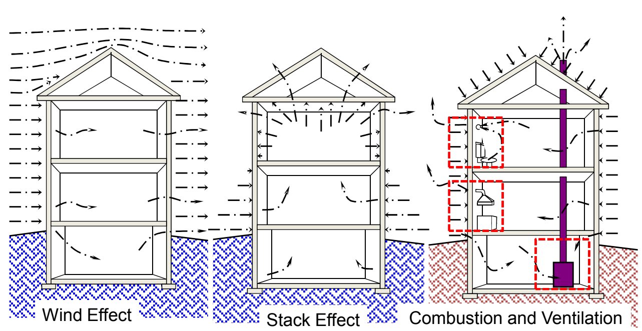
- Moisture control
  - Air leakage condensation
- Comfort and Health
  - Drafts
  - Odors, particles, gases
- Energy
  - Heat transferred with air
- Sound
- Required by some codes

If you can’t enclose air, you can’t condition it

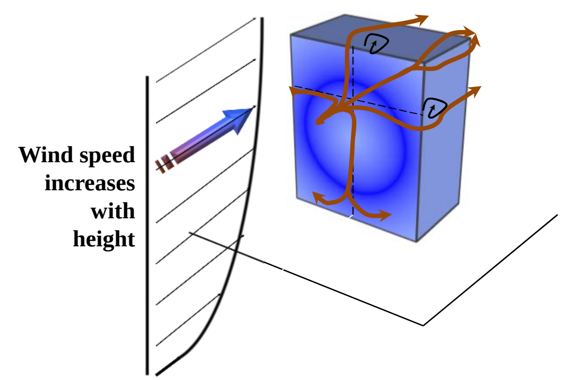
Driving Forces

- 1. Wind Pressures
- 2. Buoyancy (or stack effect)
- 3. HVAC

Driving Forces

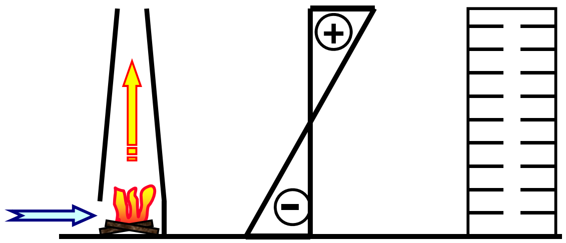


Wind Flow Patterns



Stack Effect: Cold Weather

- Hot air rises
- Tall Building in Winter = Heavy Balloon



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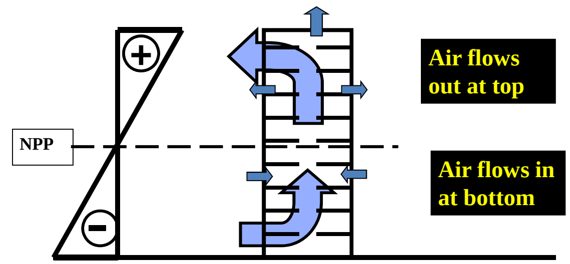
Stack Effect: Cold Weather

- “Perfect” Building equally leaky everywhere
- Neutral Pressure Plane at mid-height



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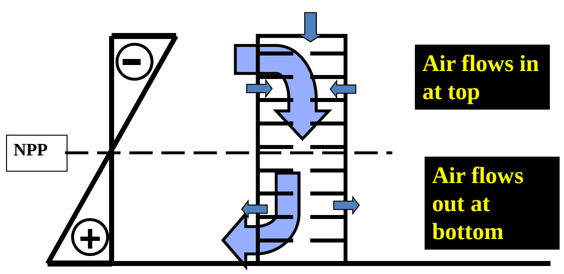
Stack Effect: Warm Weather

- “Perfect” Building equally leaky everywhere
- Neutral Pressure Plane at mid-height



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Stack Effect

- When cold (20 F) outside
  - About 4 Pa per storey (10’) of height
  - 250 Pa (Pascal) = 1 inch of water column (IWC)
- When hot (95 F) outside
  - About 1.5 Pa per storey (10’) of height
- Result
  - Revolving doors
  - We suck air from below in cold weather

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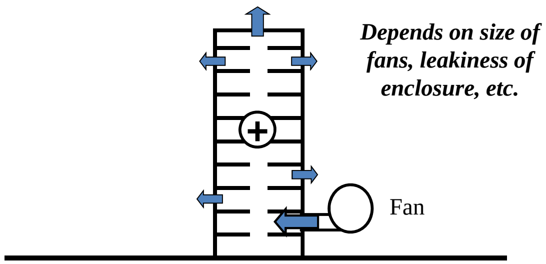
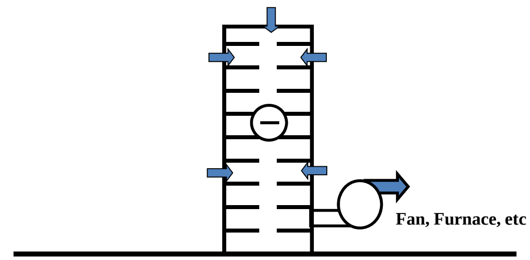
HVAC Pressurization

- More airflow forced into building than sucked out of building = Pressurization



De-Pressurization

- More airflow forced out of building than forced into building = De-Pressurization



Driving Forces

- Wind
  - Taller buildings see high pressures!
  - 2-10 Pa low bldgs, 30-200+ Pa tall buildings
- Stack Effect
  - Pressure increases directly with temperature difference and height
- HVAC
  - Depends on design and operation

Cold Weather Air Leakage-Residential

Air Leakage Condensation at Top Floors

- •Wind +
- •Stack +
- •(Rain)

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Air Barriers and Vapor Barriers

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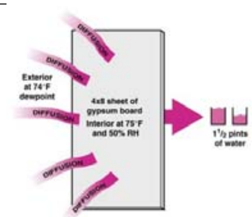
Water Vapor Transport

- Vapor Diffusion
  - more to less vapor
  - no air flow
  - flow through tiny pores
- Air Convection
  - more to less air pressure
  - flow through visible cracks and holes
  - vapor is just along for the ride



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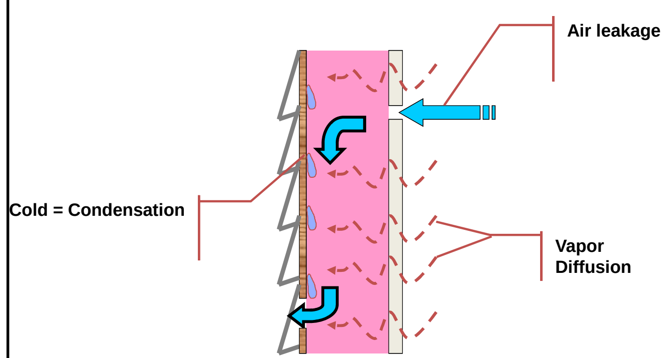
Wall w/o Insulated Sheathing



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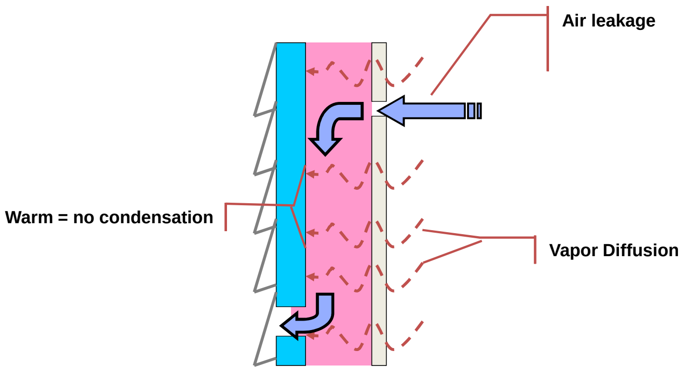
Wall with Insulated Sheathing



Vapor Barriers and the Code

- Class I: 0.1 perm or less (polyethylene)
- Class II: 0.1 < perm ≤ 1.0 perm (Kraft facing, vapor retarder paint)
- Class III: 1.0 < perm ≤ 10 perm (Latex paint)
- Polyethylene = no inward drying
- More open vapor control allows greater drying—more “forgiveness” in wall

Vapor Barriers and the Code

TABLE N1102.5.1
CLASS III VAPOR RETARDERS

Zone	Class III vapor retarders permitted for:
Marine 4	Vented cladding over OSB Vented cladding over plywood Vented cladding over fiberboard Vented cladding over gypsum Insulated sheathing with *R*-value ≥ 2.5 over 2x4 wall Insulated sheathing with *R*-value ≥ 3.75 over 2x6 wall
5	Vented cladding over OSB Vented cladding over plywood Vented cladding over fiberboard Vented cladding over gypsum Insulated sheathing with *R*-value ≥ 5 over 2x4 wall Insulated sheathing with *R*-value ≥ 7.5 over 2x6 wall
6	Vented cladding over fiberboard Vented cladding over gypsum Insulated sheathing with *R*-value ≥ 7.5 over 2x4 wall Insulated sheathing with *R*-value ≥ 11.25 over 2x6 wall
7 and 8	Insulated sheathing with *R*-value ≥ 10 over 2x4 wall Insulated sheathing with *R*-value ≥ 15 over 2x6 wall

Can just use latex paint (no vapor barrier) if you add enough insulation outside of the stud bay insulation. Safer -> controls diffusion and air leakage moisture

Cold-Climate Air Leakage Condensation

Case Study: Cold Climate Air Leakage

- Eastern Nebraska Location (Design T -5.4° F)
- Climate Zone 5A (Cold)
- Icicles coming out of soffit in wintertime
- Pressurized & humidified interior conditions

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Icicle Patterns

- Big icicles from roof edge
- Ice dam issues
- But also icicles from bottom of soffit
  - Coming out at cracks and seams

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Window Patterns

- White mineral staining on windows
- Despite big overhang
- Even ice drips of window frames

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And into the Soffit….

- Vented space, right… hey wait…
- 66-68 F and 55% relative humidity in this space… can walk into main attic from this space
- Running +9-10 Pascals WRT exterior

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Soffit and “Trough” Detail

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Soffit Exterior Disassembly

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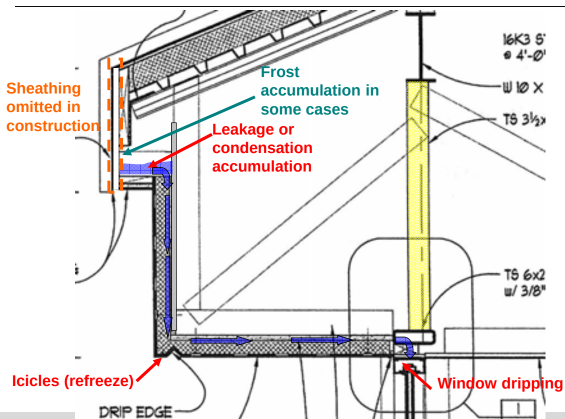
Section Detail at Soffit



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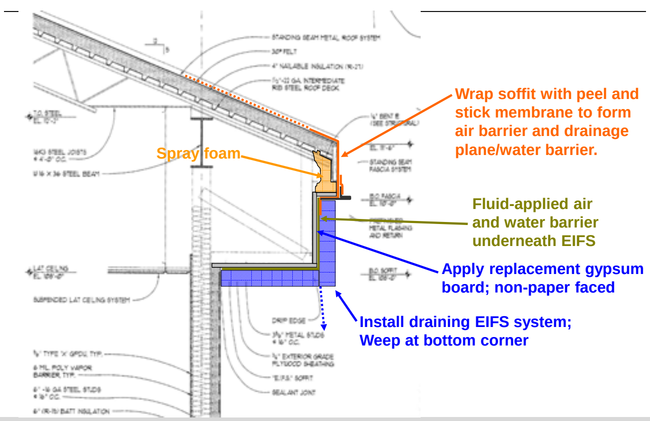
Retrofit Detail



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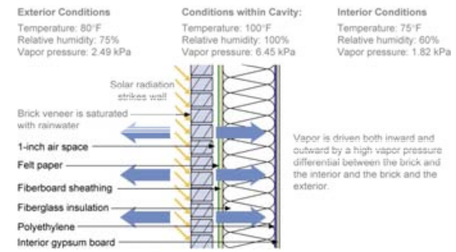
Inward Vapor Drives (Reservoir Claddings)

Inward Vapor Drive-Background



- Interior polyethylene + air conditioning → moisture accumulation.
- Ventilated drainage cavity → reduces inward drives
- Vapor “open” exterior (fiberboard, DensGlass) → higher risk
- Vapor “closed” (lower permeance) exterior (XPS) → lower risk

Inward Vapor Drive

Inward Vapor Drive

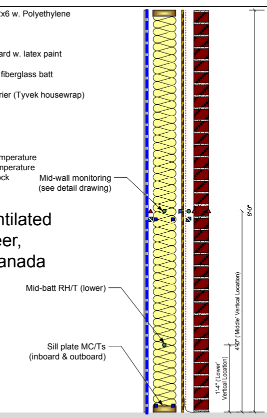
Above Grade Wall 1: 2x6 w. Polyethylene

Wall Assembly:

- ½” Gypsum wallboard w. latex paint
- 6 mil polyethylene
- 2x6 stud with R-19 fiberglass batt
- ½” OSB sheathing
- Water resistive barrier (Tyvek housewrap)
- 25 mm cavity
- Brick

Sensor Key:
- Temperature
- Relative humidity/temperature
- Moisture content/temperature
- Moisture content block

Poorly ventilated brick veneer, Ontario Canada

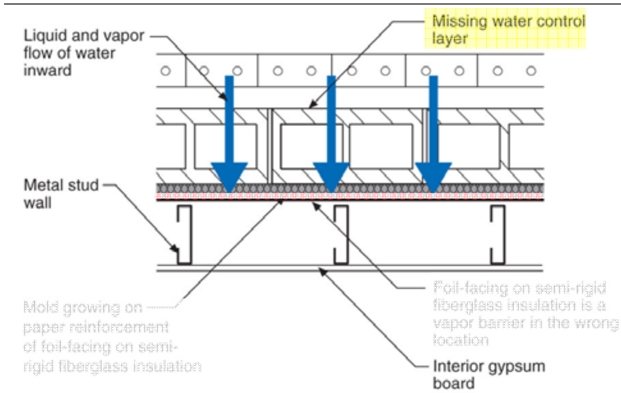


Mixed-Humid Climate Contaminant Redistribution

Mixed-Humid Climate Hospital

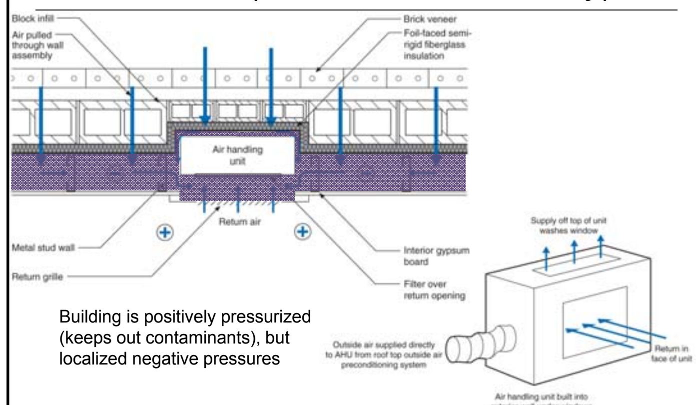
- Immunocompromised patients dying of aspergillosis
- Exposure occurred at hospital
- *Aspergillus fumigatus* grows on building materials
- Deaths concentrated in SW corner of building
- Wall construction:
  - Masonry brick veneer w. airspace
  - Block backup wall, no water control layer (drainage plane/WRB)
  - Foil-faced semi-rigid fiberglass
  - Empty steel stud cavity, gypsum board

Inward Vapor Drive Problems



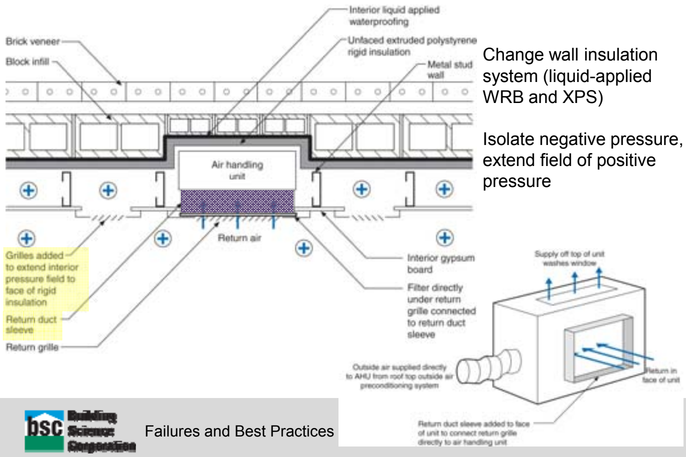
But the building is positively pressurized!

The Problem (Contaminant Pathway)



Building is positively pressurized (keeps out contaminants), but localized negative pressures

The Fix (Interior Waterproofing/Insulation)



Change wall insulation system (liquid-applied WRB and XPS)

Isolate negative pressure, extend field of positive pressure

Failures and Best Practices

The "Perfect Wall"

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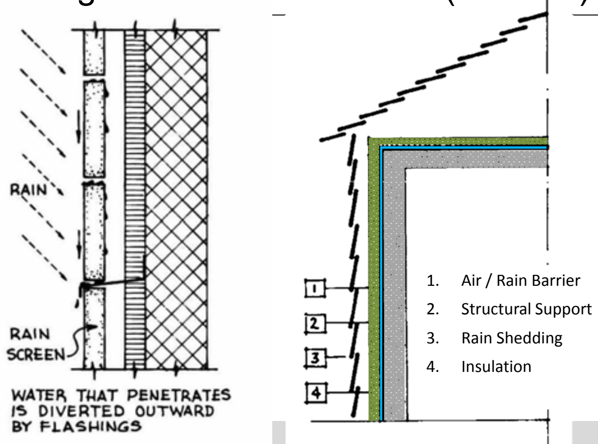
Design Info from the 1960's (Canada)



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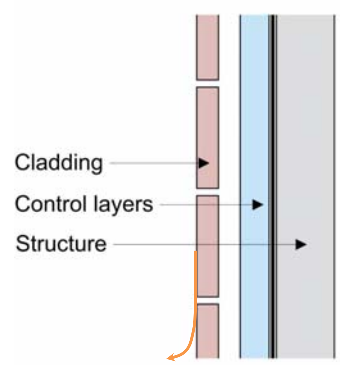
The Perfect Wall



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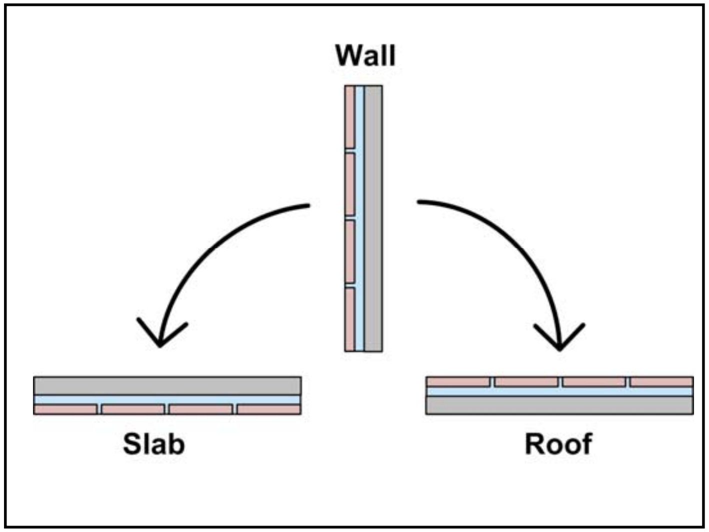
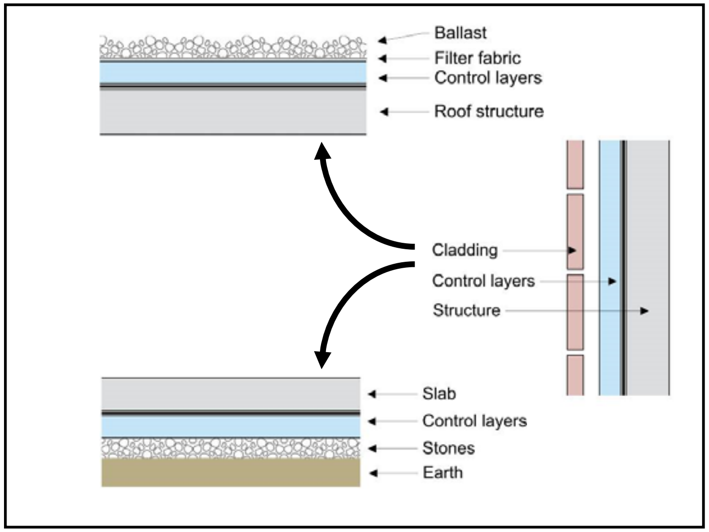
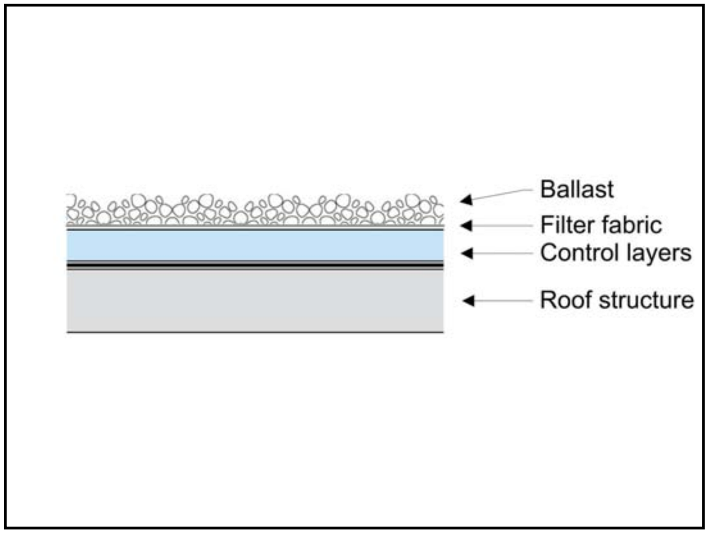
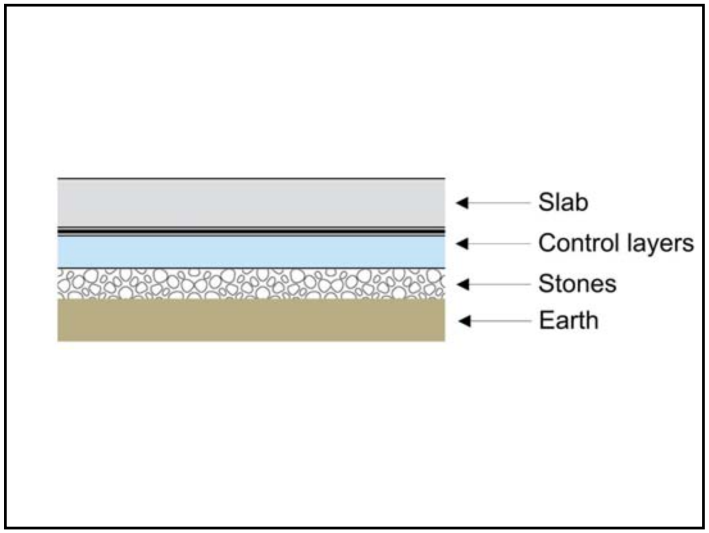
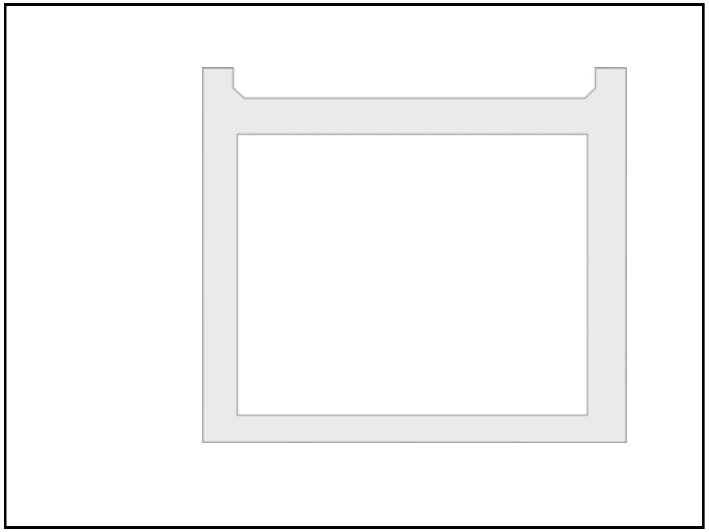
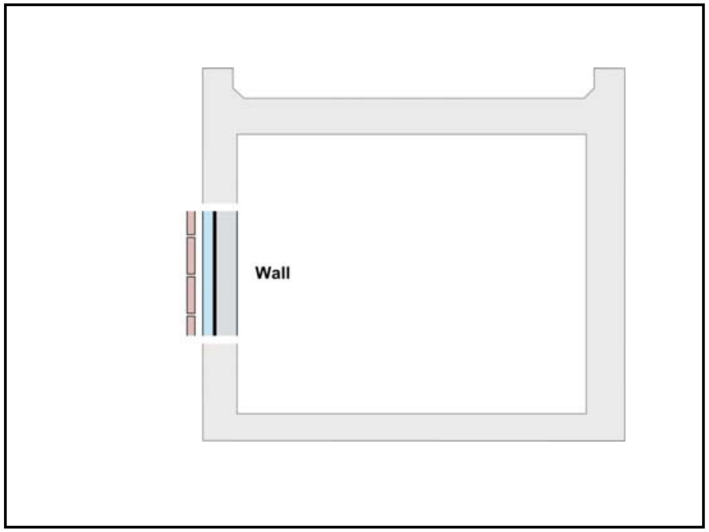

Wall
Slab
Roof

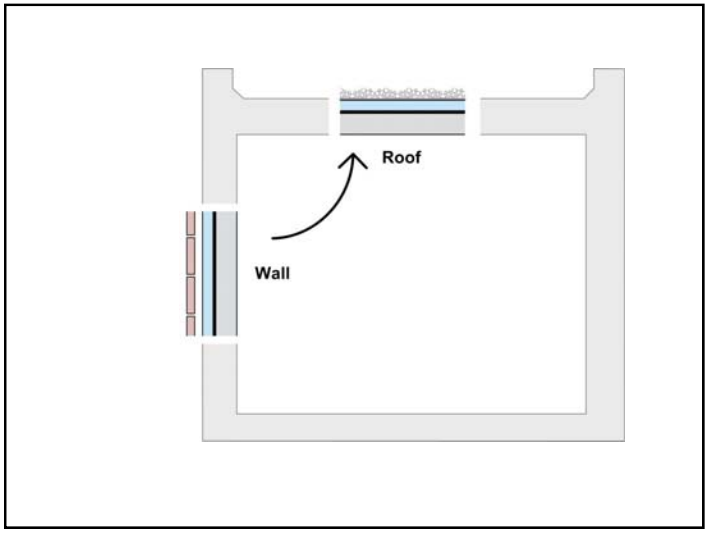

Ballast
Filter fabric
Control layers
Roof structure
Cladding
Control layers
Structure
Slab
Control layers
Stones
Earth

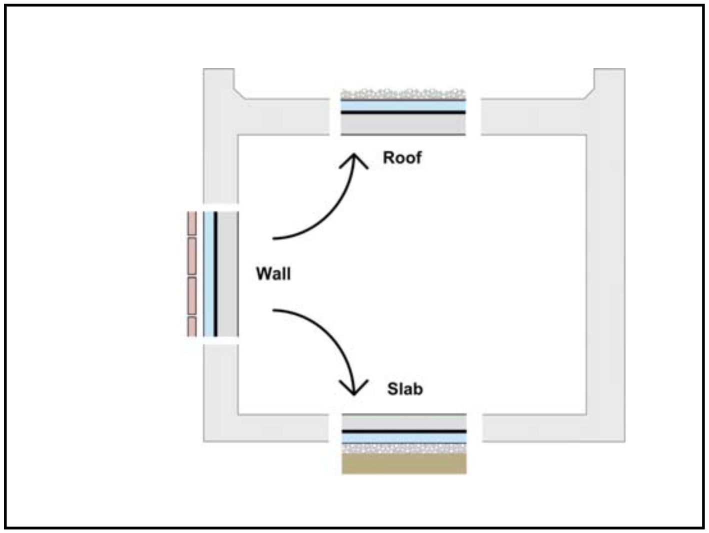

Ballast
Filter fabric
Control layers
Roof structure

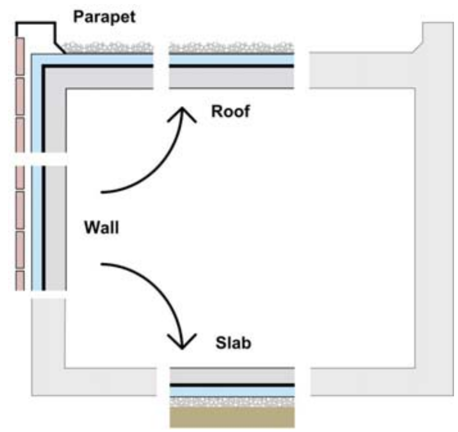

Slab
Control layers
Stones
Earth

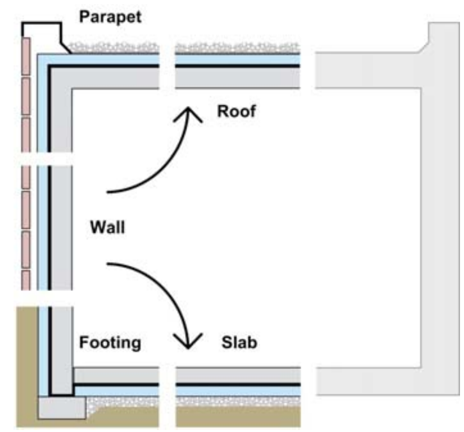


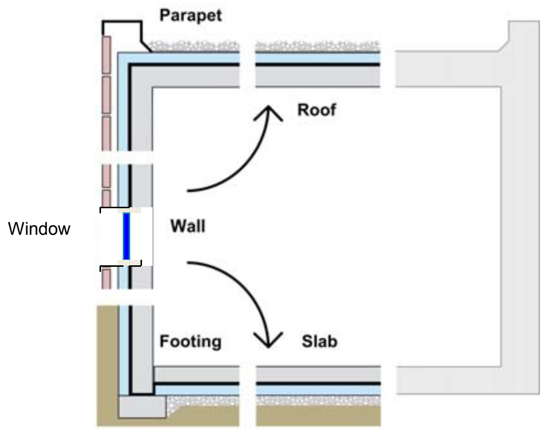

Wall


Roof
Wall

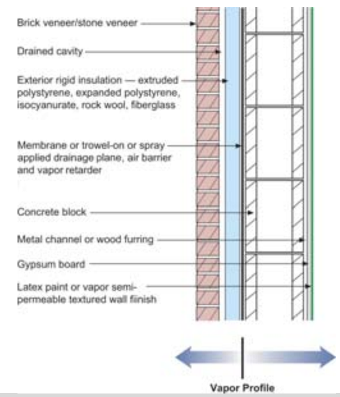

Roof
Wall
Slab







The "Perfect" Wall: Higher Performance



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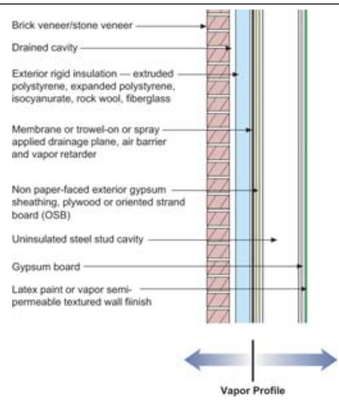
The Commercial Steel Frame Wall



"Perfect Wall" Advantages

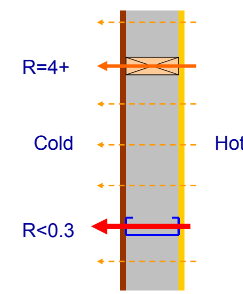
- Very robust enclosure—"500 year building"
  - Structural portion in "interior" conditions
- Institutional/long term buildings
- No risk of interstitial condensation
- Continuity of control layers
  - Continuous thermal insulation outside
  - Inspectable and simple air barrier "wrap"
  - Water control layer/WRB inspectable before insulation
- Any interior condition
- Any exterior condition

Thermal Bridging at Framing

Thermal Bridging at Steel Framing

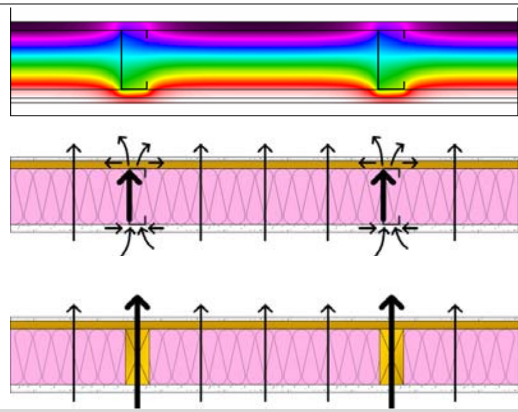
Steel is 400 times more conductive than wood

Steel studs are about 40 times thinner



A 2x6 steel stud wall 16" OC with R-19 Fiberglass Batt = effective R-9 wall assembly.

Thermal Bridging at Steel Framing



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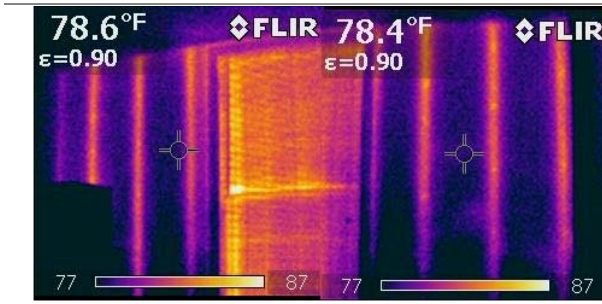
Thermal Bridging at Steel Framing



- Summertime/AC example
- Sun is hitting the wall (southeast orientation)

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Building the “Perfect Wall”

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Self-adhered membrane, XPS insulation

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Fluid-Applied Asphalt & Rock Wool

- Asphalt Drainage Plane Air Barrier
- Rock wool Insulation

Exterior Closed Cell Spray Foam

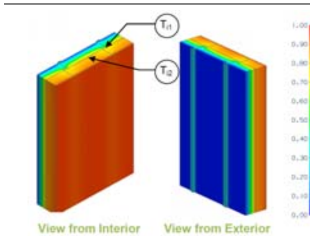
All Four Control Layers
Spray foam= air barrier & drainage plane & insulation & vapor control

Transitions, Continuity, Penetrations

Cladding Support (Z-Furring)

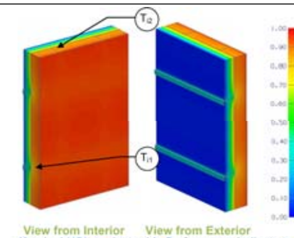
- Z-furring 16" o.c.,
- All this effort to cover up our thermal bridges with insulation… and then we punch steel through it…

Thermal Bridging at Cladding



Nominal (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft²·hr·°F / Btu (m² K / W)	R_o ft²·hr·°F / Btu (m² K / W)	U_o Btu/ft²·hr·°F (W/m² K)
R-5 (0.88)	R-8.2 (1.44)	R-6.4 (1.12)	0.157 (0.89)
R-10 (1.76)	R-13.2 (2.32)	R-8.3 (1.47)	0.120 (0.68)
R-15 (2.64)	R-18.2 (3.20)	R-9.7 (1.71)	0.103 (0.59)
R-20 (3.52)	R-23.2 (4.08)	R-11.0 (1.93)	0.091 (0.52)
R-25 (4.40)	R-28.2 (4.96)	R-12.0 (2.11)	0.084 (0.48)



Nominal (1D) vs. Assembly Performance Indicators

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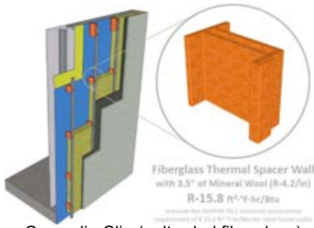
R-5 (0.88)	R-8.2 (1.44)	R-6.8 (1.21)	0.146 (0.83)
R-10 (1.76)	R-13.2 (2.32)	R-9.4 (1.66)	0.106 (0.60)
R-15 (2.64)	R-18.2 (3.20)	R-11.3 (1.99)	0.088 (0.50)
R-20 (3.52)	R-23.2 (4.08)	R-13.1 (2.31)	0.076 (0.43)
R-25 (4.40)	R-28.2 (4.96)	R-14.5 (2.56)	0.069 (0.39)

- Thermal Performance of Building Envelope Details for Mid- and High-Rise Buildings (ASHRAE 1365-RP)

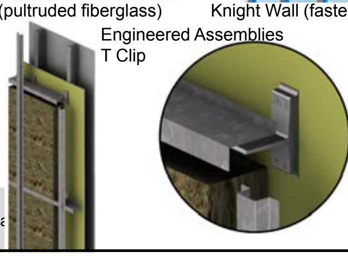
Thermally Broken Cladding Supports



Cascadia Clip (pultruded fiberglass)

Knight Wall (fasteners through foam)

Engineered Assemblies
T Clip



Hot-Humid Hospital Air Leakage Testing

Hot-Humid Climate Hospital

- Gulf Coast (DOE Zone 2A)
- Complaints of mold on interior finishes, especially vapor-impermeable surfaces (frames)
- Complaints of general interior humidity issues

Hot-Humid Climate Hospital

Mold Behind Frames (Outside Walls)

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Hot-Humid Climate Hospital

- Gulf Coast (DOE Zone 2A)
- Complaints of mold on interior finishes, especially vapor-impermeable surfaces (frames)
- Complaints of general interior humidity issues
- Real problem: unbalanced HVAC system, negative pressures
- Other side contends: air leaky building causing problem
- Windows were leaking water, but not air…
- Testing the building for air leakage

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Window Frame Disassembly

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Building Conditions

- Main space: positive pressure to outside
- Animal Lab Zone: negative pressure to inside
- Four air handlers
- 127,880 CFM total supply air
- 122,495 CFM total exhaust air
- 5,385 CFM net supply air

- Using building air handler fans to test building airtightness

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Building Systems for Air Leakage Tests

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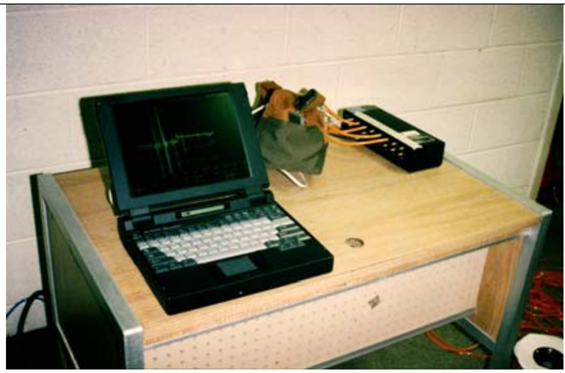
Building Systems for Air Leakage Tests



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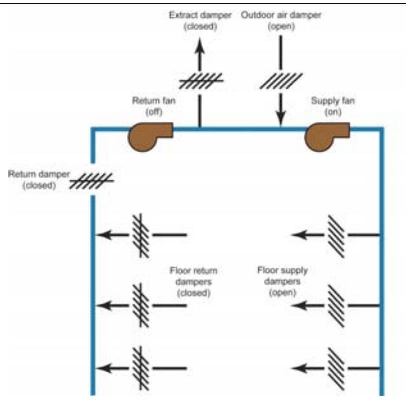
Building Systems for Air Leakage Tests



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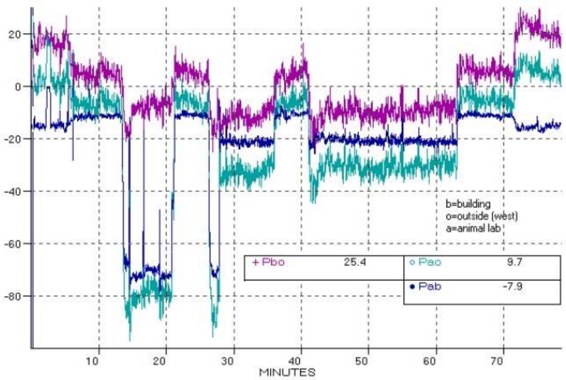
Zone-by-Zone Pressure Measurement



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Issues During Testing

- Wind
  - Varied over day, worse at higher elevations
- Occupancy/Access
  - Could only access and open/close portions of building
  - Connecting building via blocked open stairways
  - Animal laboratory at negative pressures
- Airflow data for system fans
  - Relying on test & balance reports
- Zone pressure boundaries
  - Design/drawings vs. reality

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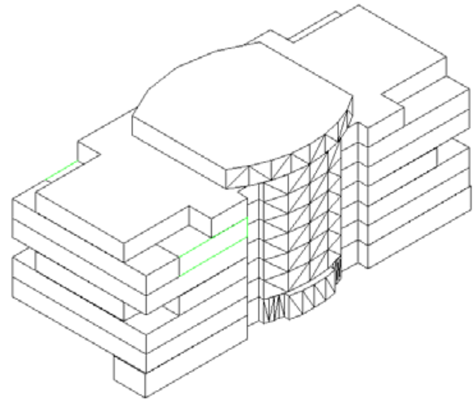
Schematic CAD Model



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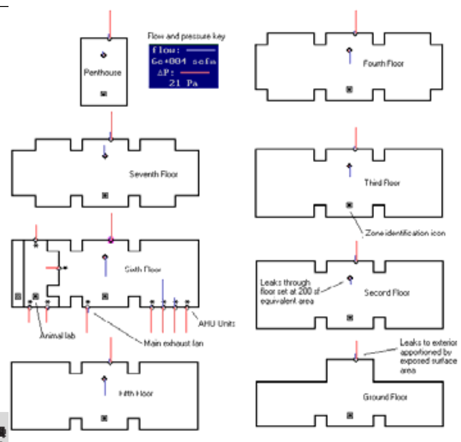
CONTAM Airflow Model



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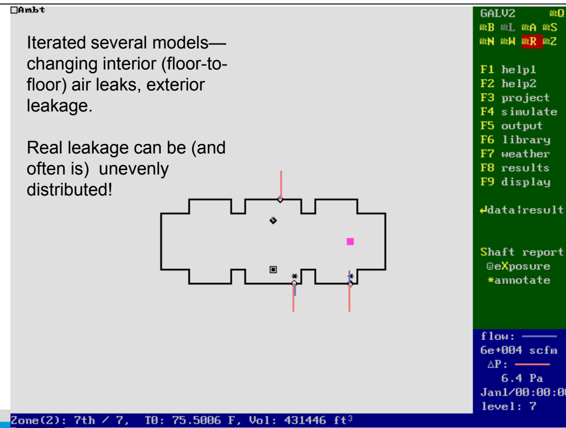
CONTAM Airflow Model



Iterated several models—changing interior (floor-to-floor) air leaks, exterior leakage.

Real leakage can be (and often is) unevenly distributed!

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Recommendations for Testing Buildings

- If using building air handlers for air leak tests:
  - Advance team: measure airflow through outside air fans (supply and exhaust) (vs. T&B report)
  - Access to as much as building as possible
  - Flexibility in schedule? (wind)
  - See CGSB Publication 149-15-96
- Recommend measurement of air leakage with dedicated equipment if possible
- Current generation of equipment and controls → great automation of testing and data collection

Airtightness Testing of Big Buildings

- Testing by WJE/Camroden/Energy Conservatory/CSG/et al.

Questions?

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This presentation will be available at http://buildingscience.com/past-events

Document Resources

- Forensic Investigations: Health Care Center
  http://buildingscience.com/project/health-care-center-0
- Forensic Investigations: Hospital Building
  http://buildingscience.com/project/hospital-building
- Building Science Insight 001: The Perfect Wall
  http://www.buildingscience.com/documents/insights/bsi-001-the-perfect-wall/
- Building Science Insight 036: Complex Three Dimensional Airflow Networks
  http://www.buildingscience.com/documents/insights/bsi-036-complex-three-dimensional-air-flow-networks/
- Building Science Insight 050: Parapets—Where Roofs Meet Walls
  http://www.buildingscience.com/documents/insights/bsi-050-parapets-where-roofs-meet-walls/
- Building Science Insight 048: Exterior Spray Foam
  http://www.buildingscience.com/documents/insights/bsi-048-exterior-spray-foam/
- Blower Door Applications Guide: Beyond Single Family Residential
  http://energyconservatory.com/wp-content/uploads/2014/07/Blower-Door-Applications-Guide-Beyond-Single-Family-Residential-Ver-1-0.pdf