Kohta Ueno

Building Science Experts' Session

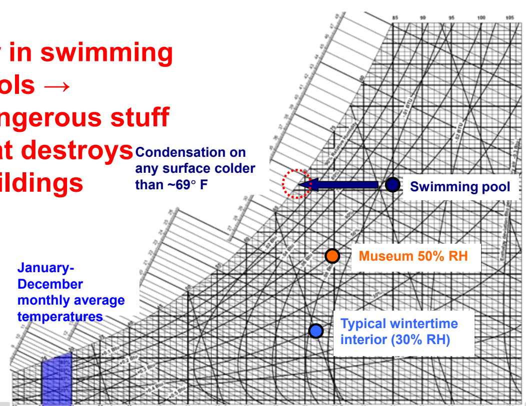
Special Use Facilities

Building Science Corporation

Swimming Pools: Basics & Assemblies

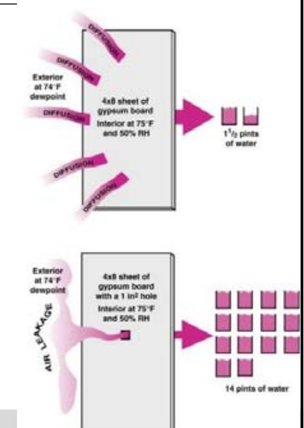
Swimming Pool Conditions

Air in swimming pools → dangerous stuff that destroys buildings

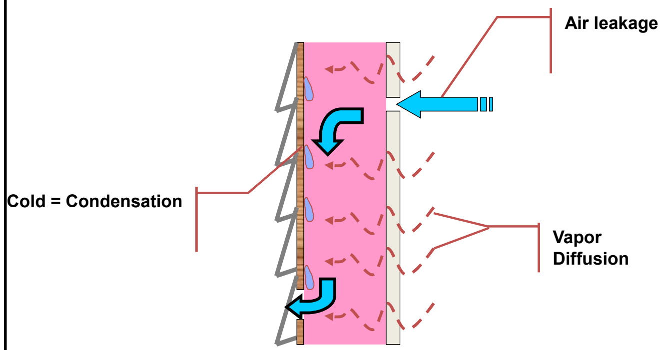


Vapor Diffusion vs. Air Leakage

- 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

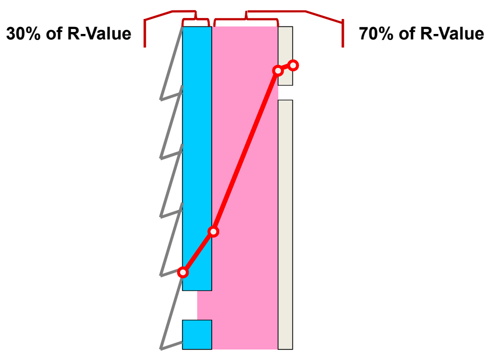


Wall w/o Insulated Sheathing

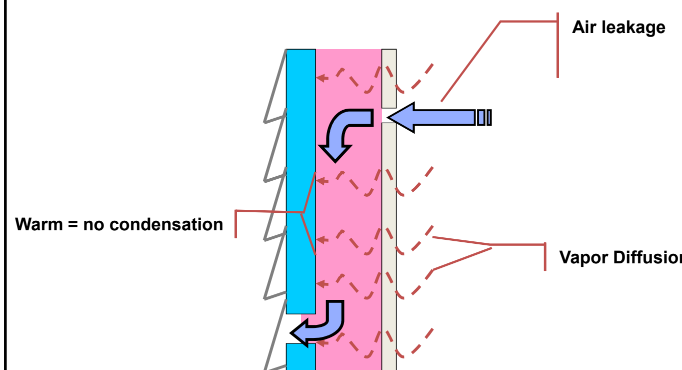


Frosting on Sheathing

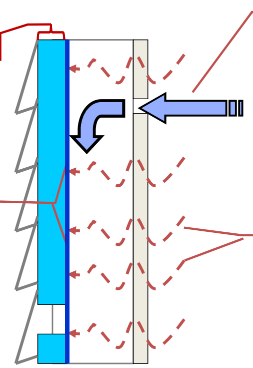
Wall with Insulated Sheathing



Wall with Insulated Sheathing

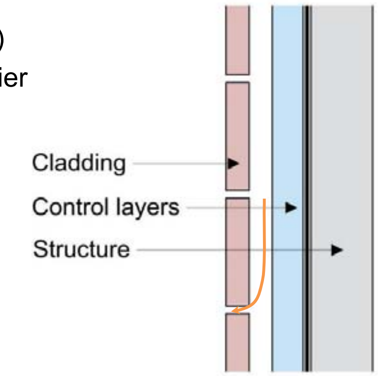


"Perfect Wall"

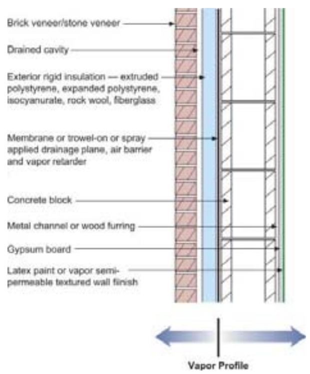


The Perfect Wall

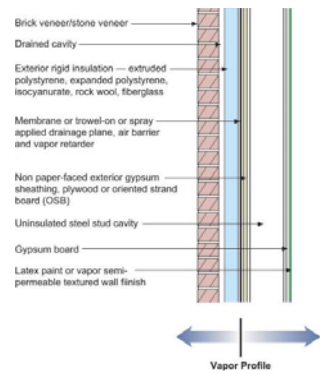
- Structure (protected)
- Air-water-vapor barrier ("Control layers")
- Insulation
- Ventilated gap ("Rainscreen")
- Exterior cladding



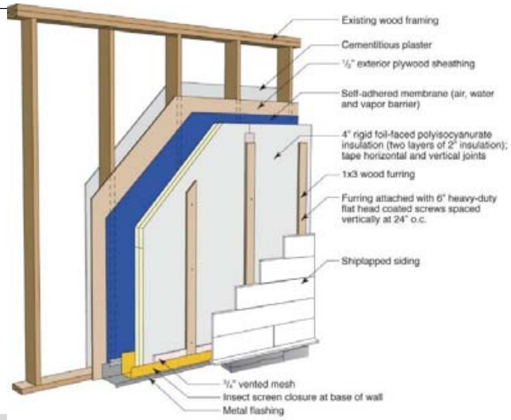
The "Perfect" Wall: Higher Performance



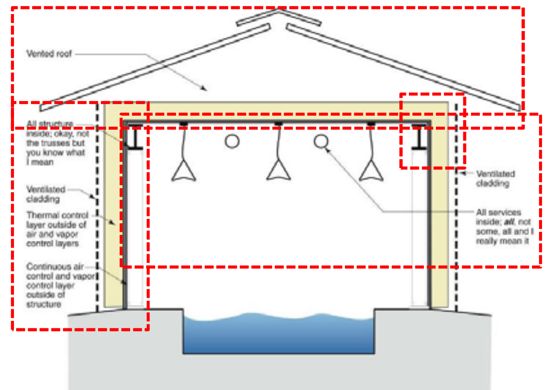
The Commercial Steel Frame Wall



Wood Frame Perfect Wall

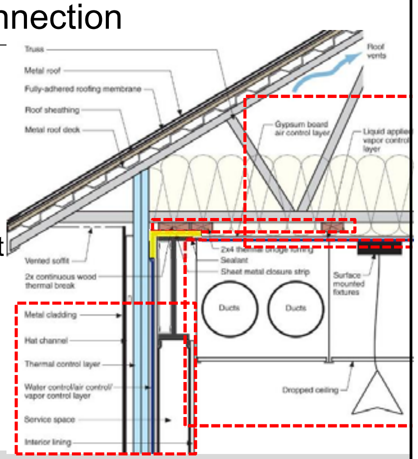


Conceptual Pool Enclosure



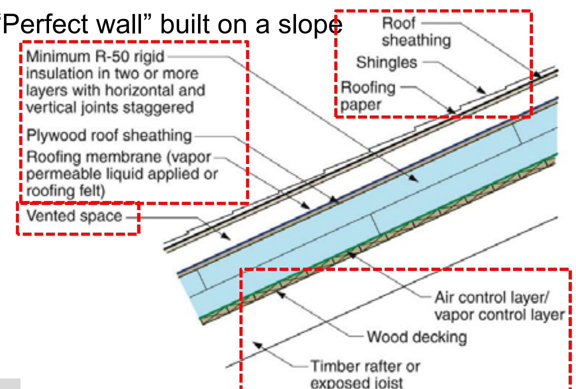
Roof-to-Wall Connection

- Perfect wall
- Vented roof
- All mechanicals inside shell
- Thermal bridging at steel truss
- Roof-to-wall air/ vapor barrier connection



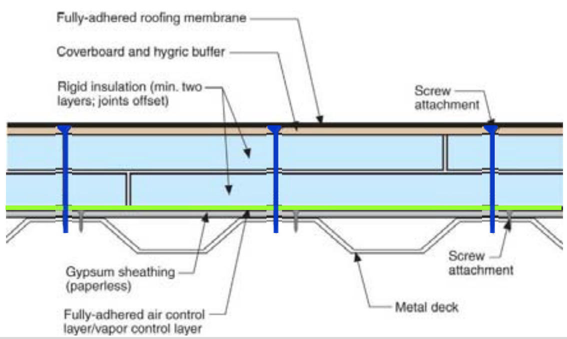
Cathedral Vented Roof

- "Perfect wall" built on a slope



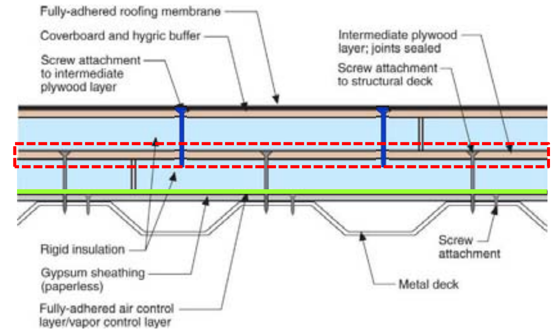
Low-Slope ("Flat") Roof

- Only works for Climate Zone 4 and warmer



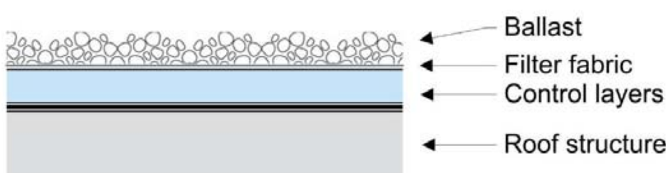
Low-Slope ("Flat") Roof

- For Climate Zone 5-ish



Inverted Membrane Roof

- Entirely safe: "perfect wall" as roof
- Top side could be ballast, pavers, "green roof"



Inverted Membrane Roof

- Entirely safe: "perfect wall" as roof
- Top side could be ballast, pavers, "green roof"

All-Foam Roof: How Thick?

TABLE R402.1.2
INSULATION AND FENESTRATION REQUIREMENTS BY COMPONENT[a]

CLIMATE ZONE	FENESTRATION U-FACTOR[b]	SKYLIGHT[b] U-FACTOR	GLAZED FENESTRATION SHGC[b, e]	CEILING R-VALUE	WOOD FRAME WALL R-VALUE	MASS WALL R-VALUE[i]	FLOOR R-VALUE	BASEMENT[c] WALL R-VALUE	SLAB[d] R-VALUE & DEPTH	CRAWL SPACE[c] WALL R-VALUE
1	NR	0.75	0.25	30	13	3/4	13	0	0	0
2	0.40	0.65	0.25	38	13	4/6	13	0	0	0
3	0.35	0.55	0.25	38	20 or 13+5[h]	8/13	19	5/13[f]	0	5/13
4 except Marine	0.35	0.55	0.40	49	20 or 13+5[h]	8/13	19	10/13	10, 2 ft	10/13
5 and Marine 4	0.32	0.55	NR	49	20 or 13+5[h]	13/17	30[g]	15/19	10, 2 ft	15/19
6	0.32	0.55	NR	49	20+5 or 13+10[h]	15/20	30[g]	15/19	10, 4 ft	15/19
7 and 8	0.32	0.55	NR	49	20+5 or 13+10[h]	19/21	38[g]	15/19	10, 4 ft	15/19

- 2015 IECC example (residential R-values)
- R-49 = 7.8 inches polyisocyanurate

All-Foam Roof: How Thick?

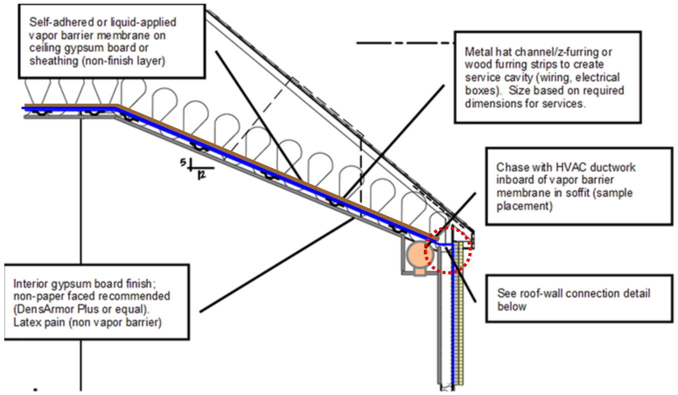
TABLE R402.1.4
EQUIVALENT U-FACTORS[a]

CLIMATE ZONE	FENESTRATION U-FACTOR	SKYLIGHT U-FACTOR	CEILING U-FACTOR	FRAME WALL U-FACTOR	MASS WALL U-FACTOR[b]	FLOOR U-FACTOR	BASEMENT WALL U-FACTOR	CRAWL SPACE WALL U-FACTOR
1	0.50	0.75	0.035	0.084	0.197	0.064	0.360	0.477
2	0.40	0.65	0.030	0.084	0.165	0.064	0.360	0.477
3	0.35	0.55	0.030	0.060	0.098	0.047	0.091[c]	0.136
4 except Marine	0.35	0.55	0.026	0.060	0.098	0.047	0.059	0.065
5 and Marine 4	0.32	0.55	0.026	0.060	0.082	0.033	0.050	0.055
6	0.32	0.55	0.026	0.045	0.060	0.033	0.050	0.055
7 and 8	0.32	0.55	0.026	0.045	0.057	0.028	0.050	0.055

- 2015 IECC Table R402.1.4 equivalent U-values
- U-0.026 = R-38.5 continuous = 6.2 inches polyisocyanurate
- Walls ~3-4 inches polyisocyanurate typical

Swimming Pools: Residential Pool Case Study

Roof-to-Wall Connection



Roof-to-Wall Air Barrier Connection

Interior & Exterior Air-Vapor Barrier

Interior & Exterior Air-Vapor Barrier

Swimming Pools: Closed Cell Spray Foam?

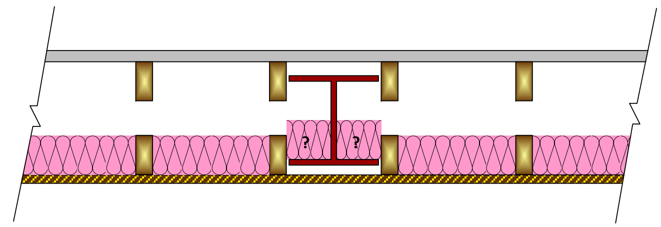
Failed Pool & Architectural Constraints



- "The pool building can't be a different size than the matching opposite wing."

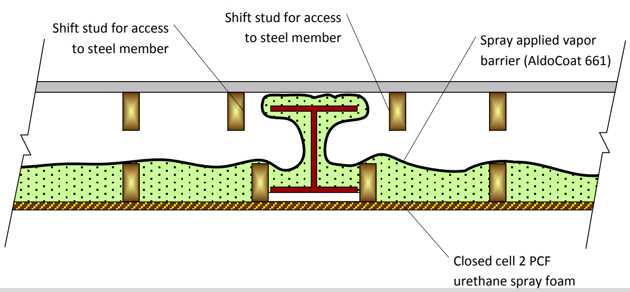
Failed Wall

- Double wall, fiberglass batts, interior plaster



Spray Foam Wall Retrofit

- ccSPF covered with vapor barrier
- Steel "buried" in ccSPF
- Permeable WRB, ventilated rainscreen



Vapor-Permeable Adhered Membrane


- Excellent air barrier
- Ventilated rainscreen—drying of sheathing
- Continued up cathedral roof assembly

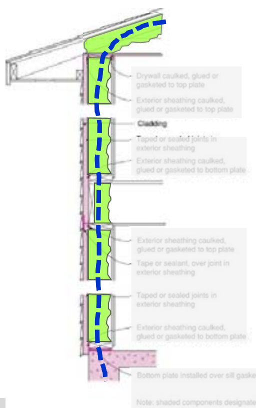
Interior Vapor Barrier Coating

- Applied to interior of ccSPF
- Needed or not?
  - 5.5” ccSPF = 0.3 perms.
  - Class I (under 0.1 perm) recommended
- Continuity of coating (air barrier)
- Problem: compatibility (real or perceived) between ccSPF & coating
  - Solution: same manufacturer for both
- Many Class I materials-VOCs, interior use IAQ

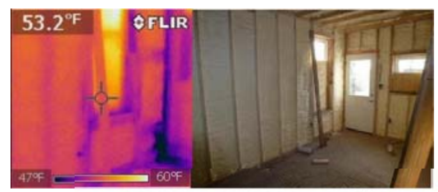
Thermal Bridging at Steel

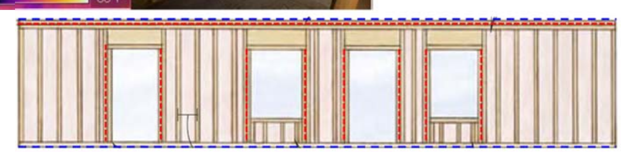
- Steel for hanging interior finishes or mechanicals
- “Bury” foam where possible, come inboard
- Still has risks

Spray Foam as an Air Barrier



Spray Foam as an Air Barrier

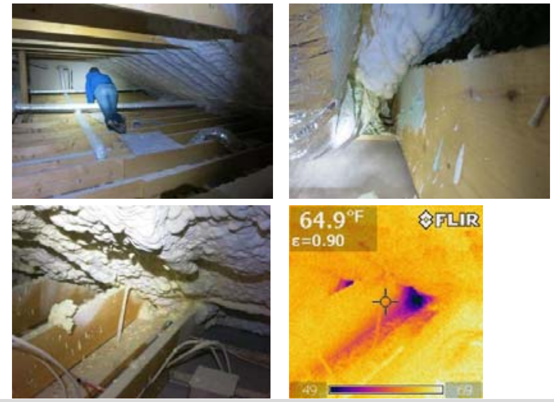




- Spray foam doesn’t air seal where it isn’t there!
- Wood-to-wood connections

Spray Foam as an Air Barrier

Spray Foam as an Air Barrier



Spray Foam Pool Enclosure: Takeaways

- Can work if “backed into a corner”
- Not recommended solution/best practice
- Risks from air leakage (imperfections in spray foam if not caught by other layer)
- Annoyances of vapor barrier coating
- Risks from thermal bridging

Swimming Pools: Case Studies & Failures

Case Study: Roof-Wall Air Barrier

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

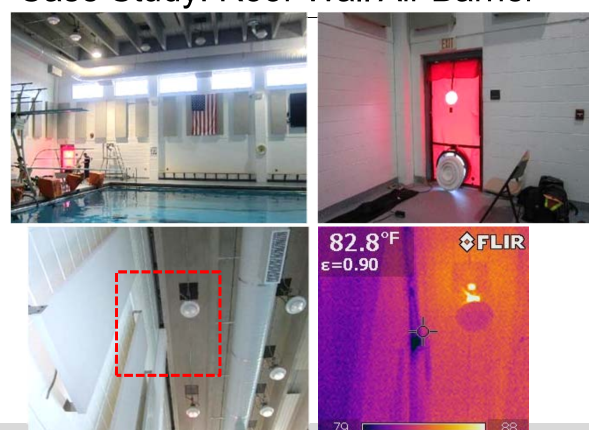
Case Study: Roof-Wall Air Barrier

- "Perfect wall"

Case Study: Roof-Wall Air Barrier

- Excellent roof (air-vapor barrier below)

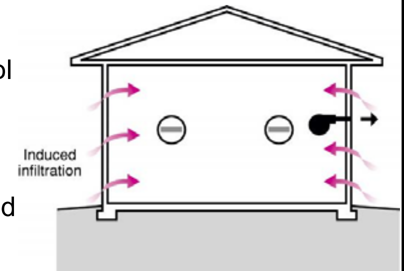
Case Study: Roof-Wall Air Barrier



Case Study: Roof-Wall Air Barrier

Run Pools at Negative Pressure

- Contains moisture (outside to inside air leakage)
- Contains odors (pool attached to rest of building)
- Tighter construction = smaller fan needed
- ASHRAE ~ -12 Pa recommended



Room Pressure Indicator

- “Ball in the wall” (medical, animal labs, etc.)

Case Study: Pressurized Pool

- Recently rebuilt NH resort pool

Case Study: Pressurized Pool

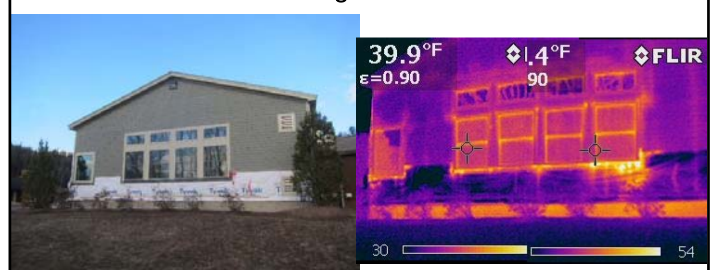
Case Study: Pressurized Pool

Case Study: Pressurized Pool

- Reused existing mechanical system (ventilation-based dehumidification, not refrigerant-based)
- Pool running at ~+25 Pascals (up to +40 Pa)

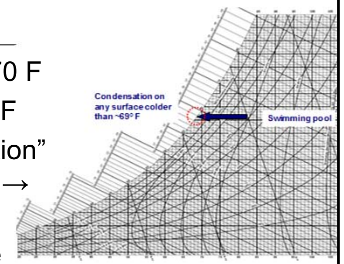
Case Study: Pressurized Pool

- Pool conditioning system improperly configured
- Pressurized pool + greater airtightness → concentrated air leakage condensation



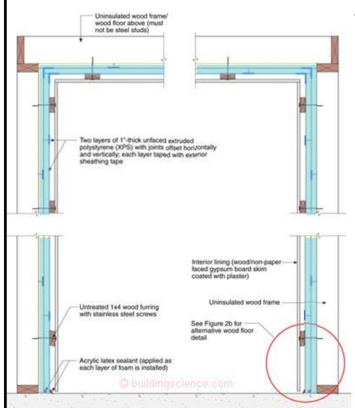
Swimming Pool: Pool-to-Interior Walls

Interior-to-Pool Walls



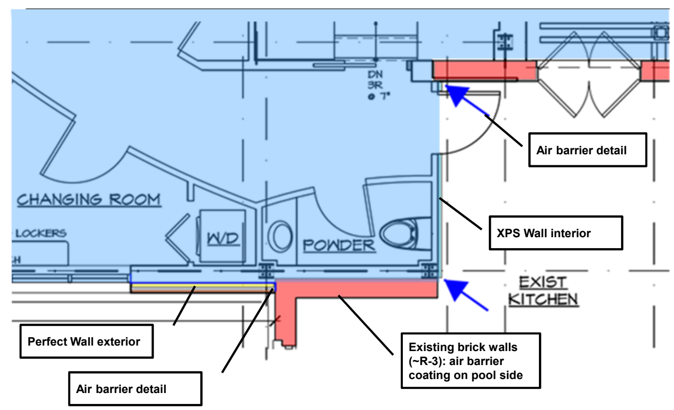
- Dewpoint of pool air is ~70 F
- Interior typically at 68-75 F
- "Cold-weather condensation" when outdoors is "warm" → relatively low risk
- Condensation & moisture resistant assemblies recommended
- Double glazed for pool-to-interior windows (eliminates window fogging), or blowing heat
- Airtightness—connection to exterior air barrier

Wine Room Enclosure Assembly



- XPS on one side of empty stud frame
- Taped joints for air barrier continuity
- Furring for interior finishes
- Challenges at ceiling: mechanical penetrations & sequencing
- ccSPF also an option

Interior-to-Pool Wall



Swimming Pool: Takeaways

Pool Enclosure Takeaways

- Air inside pool is "dangerous stuff"
- Perfect wall/roof/slab enclosure ideal
- Contain with negative pressurization (exhaust)
- Pool dehumidification system
  - Limit interior to 50-60% RH. Must run 24/7/365
  - Pool covers will reduce the load
- Windows will always condense (unless triple)
  - Detail assuming interior condensation
- Air leakage testing at air barrier completion
  - Quality control for air barrier failures
  - Can estimate size of required exhaust fan (~ -12 Pa)

Museums

Werner Otto Hall (Harvard)-1991

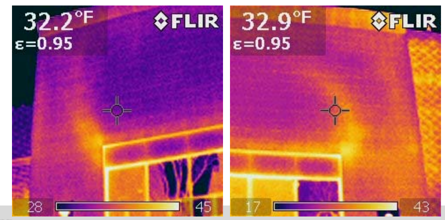
- Was demolished after 19 years of service
- Pressurized / 50% RH
- Wintertime condensation, walls soaked through
- Icicles from parapets
- Glass block efflorescence

- Harvard sued architect & contractor in 1996
- Repairs done; still demolished in 2010

Werner Otto Hall (Harvard)-2008

- Metal panel cladding, sealed joints
- Creates its own weeps!

Werner Otto Hall (Harvard)-2008



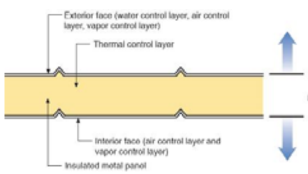
Museum Storage Building (Insulated Metal Panel)

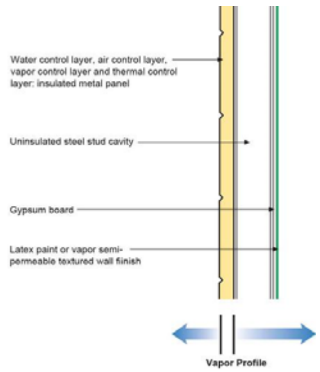
Museum Storage Building

- Constant humidified 50% RH (art storage)
- Insulated metal panel (IMP) walls and roofs, simple design
- Climate Zone 6A
- Dripping from ceiling during early fall commissioning
- Dripping stopped with RH dropped to 20%
- Seasonal problems

IMPs and the Perfect Wall

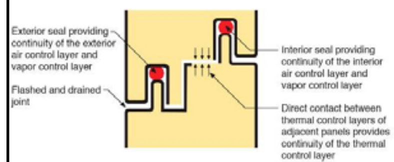
- BSI-090: Joseph Haydn Does The Perfect Wall
- Perfect air/vapor barriers on both sides of panel

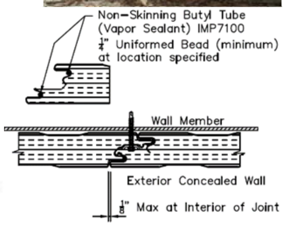




IMP Wall Panel Joints

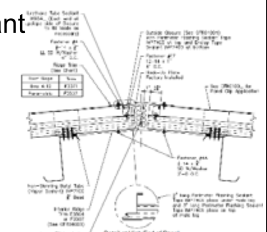
- Double sealant joint
- Thermal break at panel edge
- Drained and "flashed" joint (rain has to push uphill at horizontal joints)

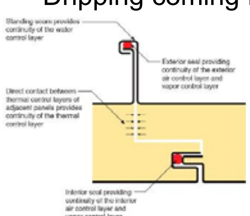




IMP Roof Panel Joints

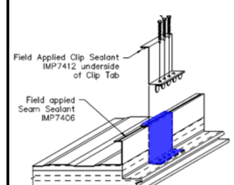
- Standing seam w. double sealant joint, thermally broken
- Ridge detail (ccSPF)
- Panel end lap details
- Dripping coming from end laps

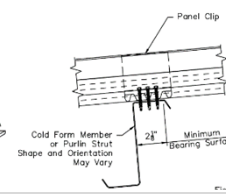




Minor Thermal Bridging at Roof Clips

- "Grid of dots" on ceiling
- Attachment clips bridge through most of insulation
- Not the source of dripping problems

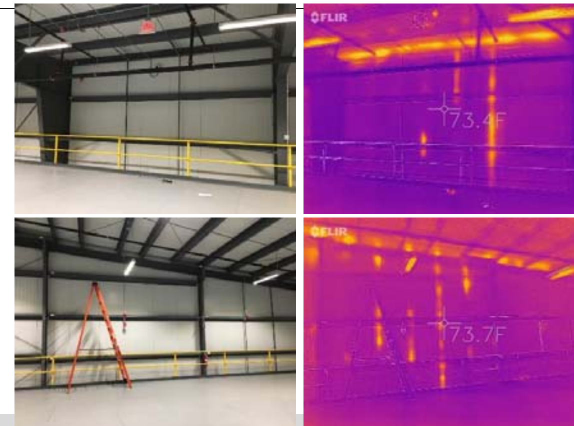




Depressurization Testing

- Depressurized to -60 Pa
- Infrared flow visualization (warm weather outdoors)
- Recommended as quality control during construction

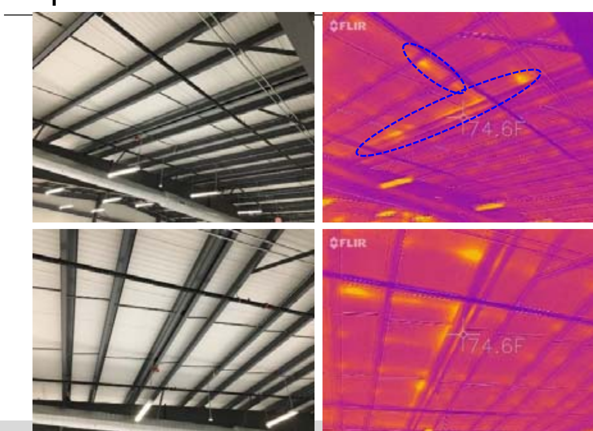
Depressurization Flow Visualization



Depressurization Flow Measurement

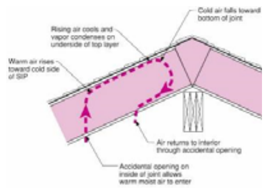
- Some seams airtight, others leaky
- Airflow 100-300 FPM/feet per minute
- Not obvious from visual inspections

Depressurization Flow Visualization

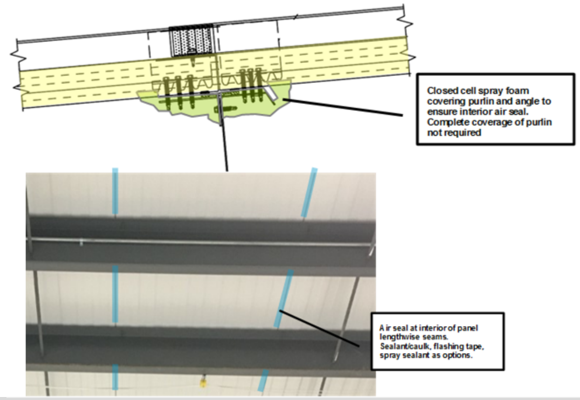


Roof Dripping Causes

- Interior-to-exterior air leaks (from IR visualization)
- Eave (roof-to-wall) air leaks
- Interior-to-interior air leaks also could be contributing (like SIPS panels)
  - Convective looping

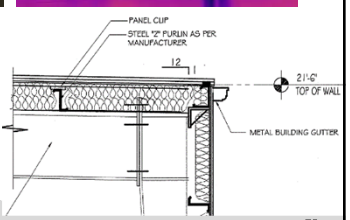


Retrofit Details (Roof Field)



"Bag and Sag" Roof for Comparison

- Fiberglass rolls with polyethylene facer
- Steel Z purlins
- Massive condensation in winter-unusable at 50%



Museum Building Takeaways

- 70F / 50% RH very risky (especially cold climates)
- Insulated metal panel good solution for high-risk buildings, BUT
- Risks are at panel seams & connections
- Quality control critical
  - Building outdoors in Climate Zone 6A
- IMP seams can't be visually inspected after construction
- Air leakage testing as part of commissioning?
- Or just specify Perfect Wall?

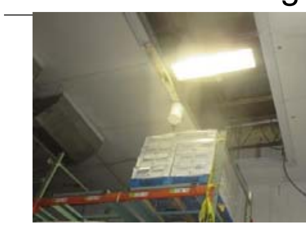
Refrigerated Warehouses

Refrigerated Warehouses

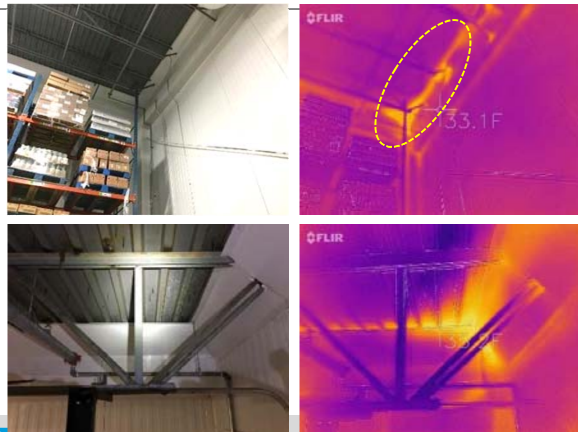
- Multiple investigations
- Refrigerated food distribution centers/warehouses
- Entire space running 0-30 F
- Typical walls IMP or IMP inboard of existing CMU
- Typical roofs metal deck, insulation, single-ply membrane

Drips from Ceiling

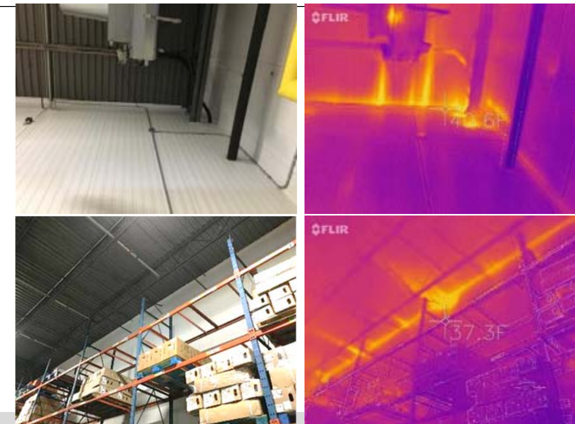
Icicles from Ceiling



Infrared Visualization of Air Leaks



Infrared Visualization of Air Leaks

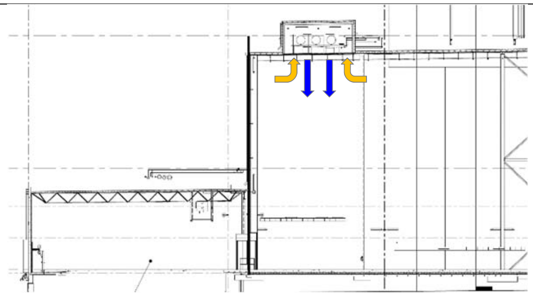


Infrared Visualization of Air Leaks

Airflow Measurement

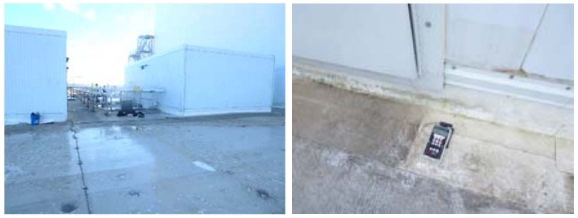
- Airflow below measurements limits (40 FPM)
- But no other explanation: moisture-laden air into cold spaces

Mechanical Penthouses



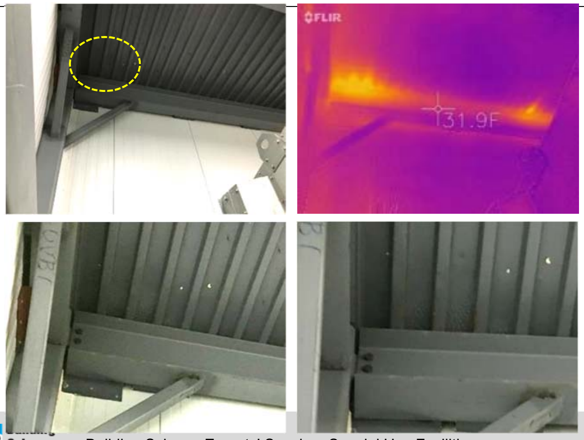
- Cooling equipment in rooftop penthouse
- Penthouse acts as return plenum open to warehouse below

Mechanical Penthouses



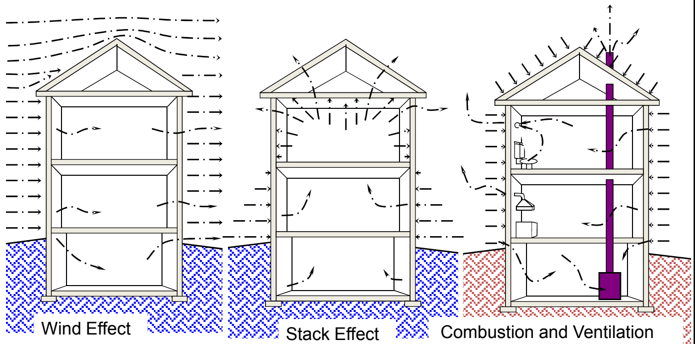
- Penthouses operate at negative pressures
- Penthouses are taller than rest of warehouse

Mechanical Penthouses

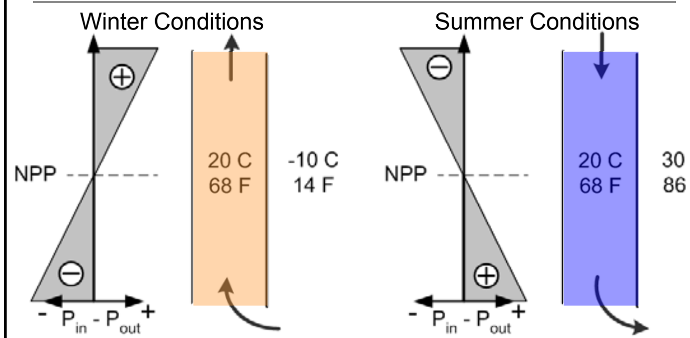


Refrigerated Warehouses and Stack Effect

Driving Forces



Stack Effect (Winter & Summer)

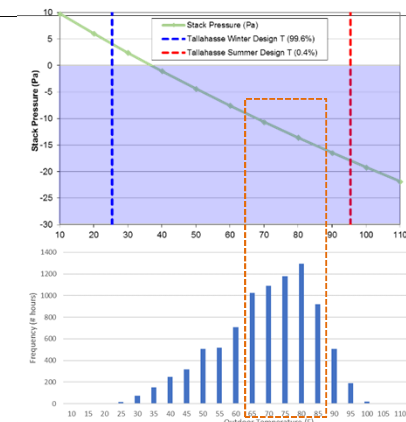


- Theoretical open tube
- NPP = neutral pressure plane

Stack Effect

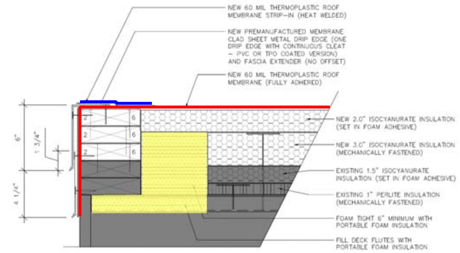
- Stack calculated based on:
  - Temperature difference
  - Height of open "stack" (taller buildings = more stack)
- Typically a problem in cold climates/winters
  - Assume ~70F indoors
  - Cold winter @ 0F, ΔT = 70F
  - Hot summer @ 100F, ΔT = 30F
- Freezer warehouses are different!
  - Assume ~10F indoors
  - Hot summer @ 100F, ΔT = 90F

Stack Effect Calculation



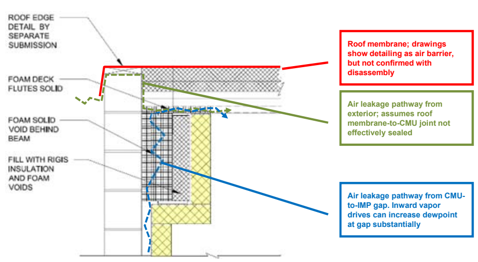
Refrigerated Warehouses Details & Solutions

Detailing: Roof Edge



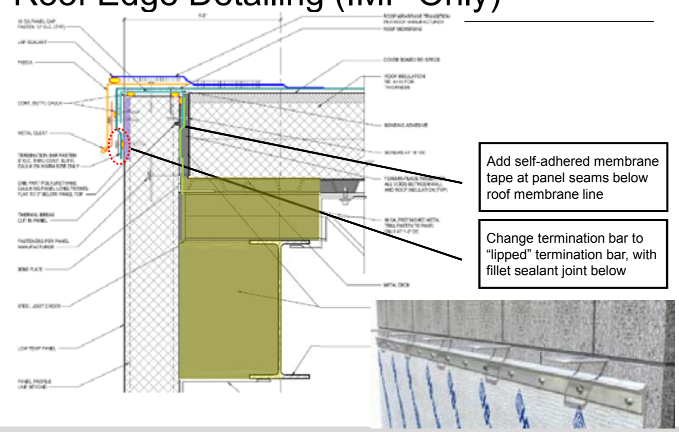
- Relies on spray foam for air seal
- Source of moisture = exterior air
- Roof membrane should be air/vapor barrier here

Roof Edge Air Leak (CMU + IMP Wall)

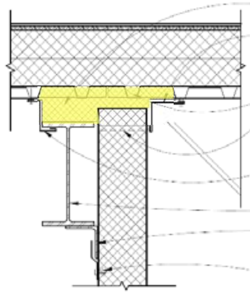


- Was roof membrane detailed as air barrier?
- Reliance on ccSPF "blind" for air seal
- Problems worst at corners & transitions

Roof Edge Detailing (IMP Only)



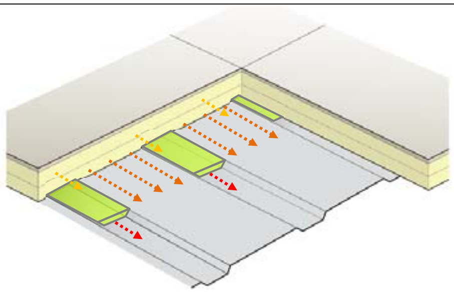
Demising Walls (Cold-to-Warm)



- Calls for spray foam above & below metal deck
- Condensation problems

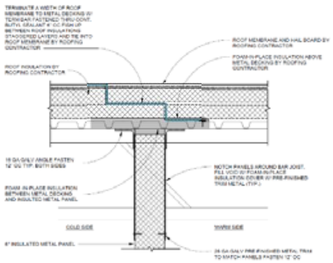
Demising Walls (Cold-to-Warm)

Air Leakage Through Roof "Sandwich"



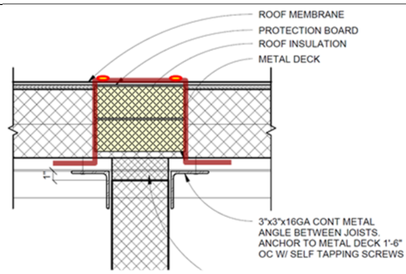
- Air leakage deck-to-insulation
- Air leakage at polyiso layers
- Air leakage through "blind" ccSPF detail

Demising Walls (Cold-to-Warm)



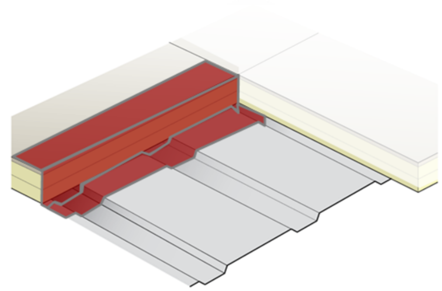
- "Zig-zag" membrane through roof layers
- Termination bar to metal deck

Demising Walls (Roof Dam Detail)



- “Dam” detail within roof assembly
- Sealant from dam to roof membrane

Demising Walls (Roof Dam Detail)



- Self-adhered or fluid-applied membrane
- Has to conform to deck flutes
- Has to be applied to low temperature surfaces

Refrigerated Warehouses Takeaways

- Leakage of warm humid outdoor air can cause major problems
- Huge air pressure pulling outdoor air in at top of building, worst in summer (high ΔT, high DP)
- Can’t neutralize with pressurization
- Relying on spray foam detailing problematic
- Membranes and sealants, termination bars
- Air leakage testing as quality control tool

Questions?

Kohta Ueno
kohta (at sign) buildingscience dot com

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