Swimming Pools: Basics & Assemblies

Swimming Pool Conditions

Air in swimming pools → dangerous stuff that destroys buildings

January-December monthly average temperatures

Museum 50% RH

Swimming pool

Condensation on any surface colder than ~69°F

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

- Air leakage
- Cold = Condensation
- Vapor Diffusion

Wall with Insulated Sheathing

- 30% of R-Value
- 70% of R-Value

Frosting on Sheathing

- Warm = no condensation
- Vapor Diffusion
The Perfect Wall

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

The Perfect Wall: Higher Performance

- Wall system components
- Ventilated gap ("Rainscreen")
- Insulation
- Exterior cladding
Wood Frame Perfect Wall

- Existing wood framing
- Plasticizer on wood shingles
- Soft rubber membranes (ac, water, and vapor barrier)
- 4" rigid hot melt polyisocyanurate insulation (then sheated with 1" isolation) tape horizontal and vertical joints
- Steel truss
- Furring attached with 6" furred-out flat back centered across spaced vertically at 24" c.c.
- Shiplap siding

Conceptual Pool Enclosure

- Vented roof
- Negative pressure to prevent water entry
- Thermal screen (not shown)
- Continuous air barrier under the roof

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
  - Minimum R-50 rigid insulation in two or more layers with horizontal and vertical joints staggered
  - Plywood roof sheathing
  - Roofing membrane (vapor permeable liquid applied or roofing felt)
  - Wall control layers
  - Air control layer/vapor control layer
  - Wood decking
  - Timber roller or gravel out
Low-Slope ("Flat") Roof

- Only works for Climate Zone 4 and warmer

Inverted Membrane Roof

- Entirely safe: “perfect wall” as roof
- Top side could be ballast, pavers, “green roof”
All-Foam Roof: How Thick?

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

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

Swimming Pools: Closed Cell Spray Foam?
Failed Pool & Architectural Constraints

- “The pool building can’t be a different size than the matching opposite wing.”

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

Failed Wall

- Double wall, fiberglass batts, interior plaster
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 doesn’t air seal where it isn’t there!
- Wood-to-wood connections
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, re-clad
- 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)
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

- 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

- 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 Walls

- Exterior XPS Wall
- Existing brick walls (~R-3): air barrier coating on pool side
- ccSPF also an option

Interior-to-Pool Wall

- Air barrier detail
- XPS Wall interior
- Existing brick walls (~R-3): air barrier coating on pool side
Swimming Pool: 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
Museum Storage Building (Insulated Metal Panel)

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

- 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

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

“Bag and Sag” Roof for Comparison

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

Retrofit Details (Roof Field)

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

- 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
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

Refrigerated Warehouses and Stack Effect
**Driving Forces**

- Wind Effect
- Stack Effect
- Combustion and Ventilation

**Stack Effect (Winter & Summer)**

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

**Stack Effect Calculation**
Refrigerated Warehouses Details & Solutions

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

Detailing: Roof Edge

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

Roof Edge Detailing (IMP Only)

- Change termination bar to "lipped" termination bar, with fillet sealant joint below
- Add self-adhered membrane tape at panel seams below roof membrane line
- "Tipped" termination bar, with first sealant joint below

Roof Edge Air Leak (CMU + IMP Wall)

- Air leakage pathway from exterior; assumes roof membrane-to-CMU joint not effectively sealed
- Inward vapor drives can increase dewpoint at gap substantially
Demising Walls (Cold-to-Warm)

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

Demising Walls (Cold-to-Warm)

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

Air Leakage Through Roof “Sandwich”

- Air leakage deck-to-insulation
- Air leakage at polyiso layers
- Air leakage through “blind” ccSPF detail
Demising Walls (Roof Dam Detail)

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

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 $\Delta T$, 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