Moisture in Concrete Roof Decks and How to Evaluate its Effect on Roofing Systems

JOE PIÑON

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RDH Building Science – Who We Are

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- 170+ staff in 8 offices
  - Canadian offices: Vancouver, Victoria, Courtney, Toronto, Waterloo (lab) (merger with John Straube's Building Science Consulting Inc.)
  - US offices: Seattle, Portland, SF Bay (Oakland)
- All Focused in Building Science
  - Existing Buildings
  - New Building Consulting
  - Research & Forensics

Research Effort by Simpson Gumpertz & Heger (SGH)

- → **Stephen Condren:** Roofing Technology
- → **Paul Scheiner:** Concrete Technology
- → **Joe Piñon:** Building Science

Learning Objectives

1. Review basic concrete properties with respect to water content.
2. Discuss the quantity of water in various types of concrete after placement and curing.
3. Review the drying process, the water remaining in a deck at the time the roofing system is likely to be installed, and its effect on roofing systems in different climates.
4. Describe historical changes in roofing designs and materials that make current roofing systems more susceptible to concrete moisture.
5. Discuss the importance of hygrothermal modeling and engineering analysis in roof design.

Concrete Basic Ingredients

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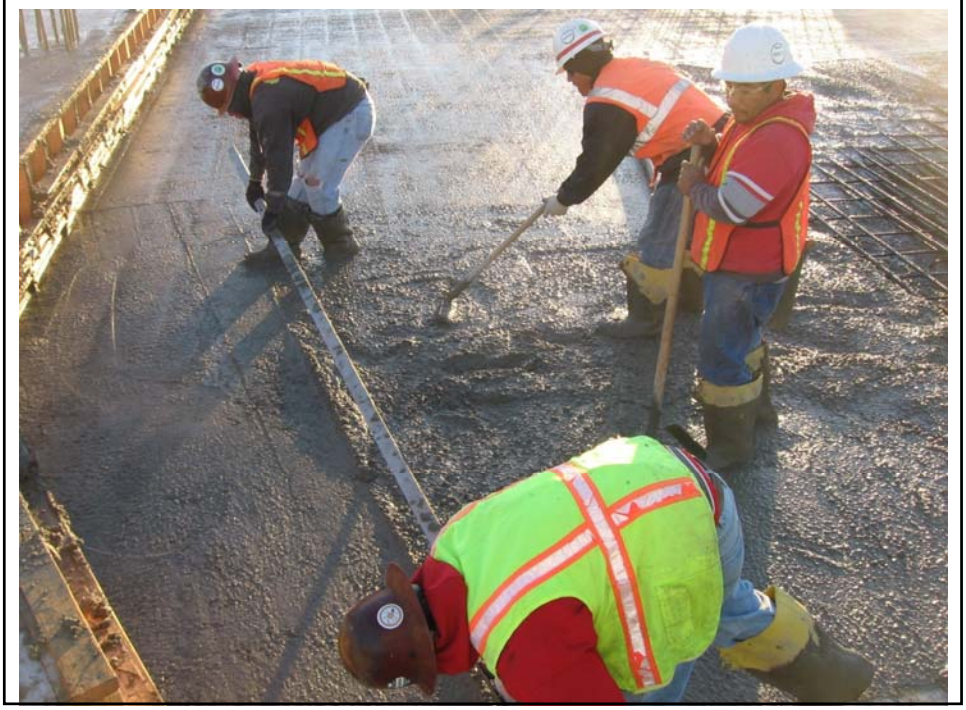
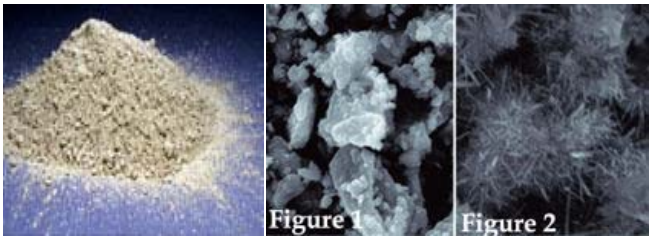
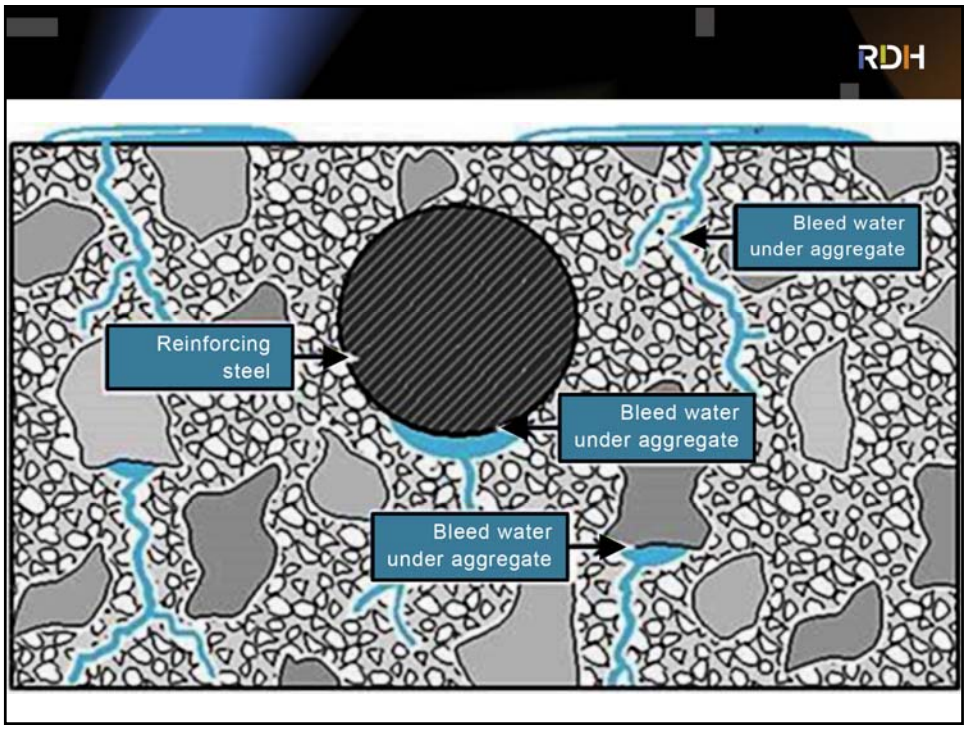


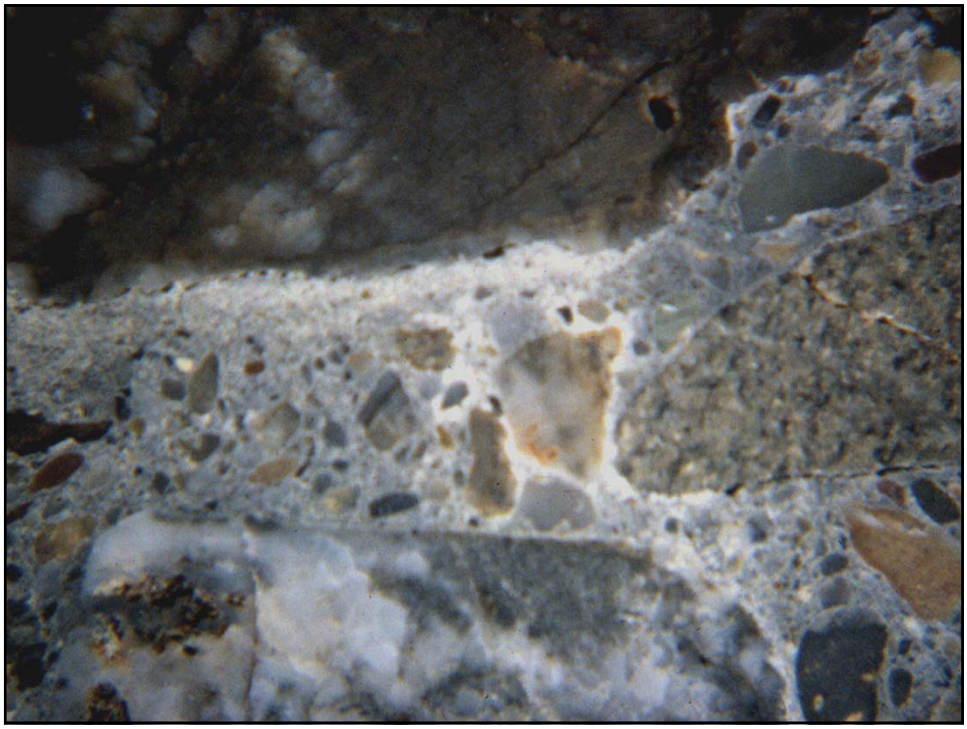
Basic Cement Reaction



Cement + Water
H_20 →

Calcium Silicate Hydrate + Calcium Hydroxide
CSH $Ca(OH)_2$





Amount of Free Water in New Concrete

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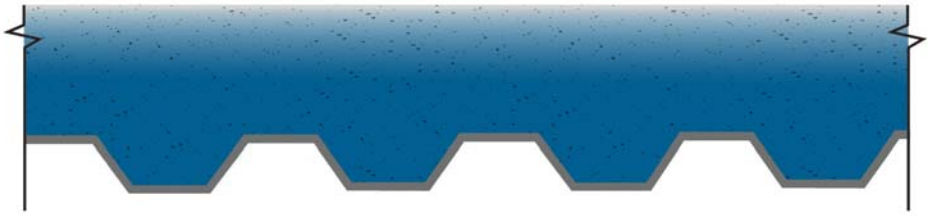
- Batch Water – hydration + water in aggregates

$$(0.40 \text{ to } 0.55\ {}^{w}/_{c}) - 0.25\ {}^{w}/_{c} + \begin{cases} 0.03\ {}^{w}/_{c} \cdots (\textit{normal weight aggregate}) \\ 0.12\ {}^{w}/_{c} \cdots (\textit{lightweight aggregate with 10\% absorption by weight}) \\ 0.22\ {}^{w}/_{c} \cdots (\textit{lightweight aggregate with 20\% absorption by weight}) \end{cases}$$

- **Free Water in a 6 in. Thick Concrete Deck:**
  0.15 w/c to 0.50 w/c = **0.9 to 2.6 quarts / sf**

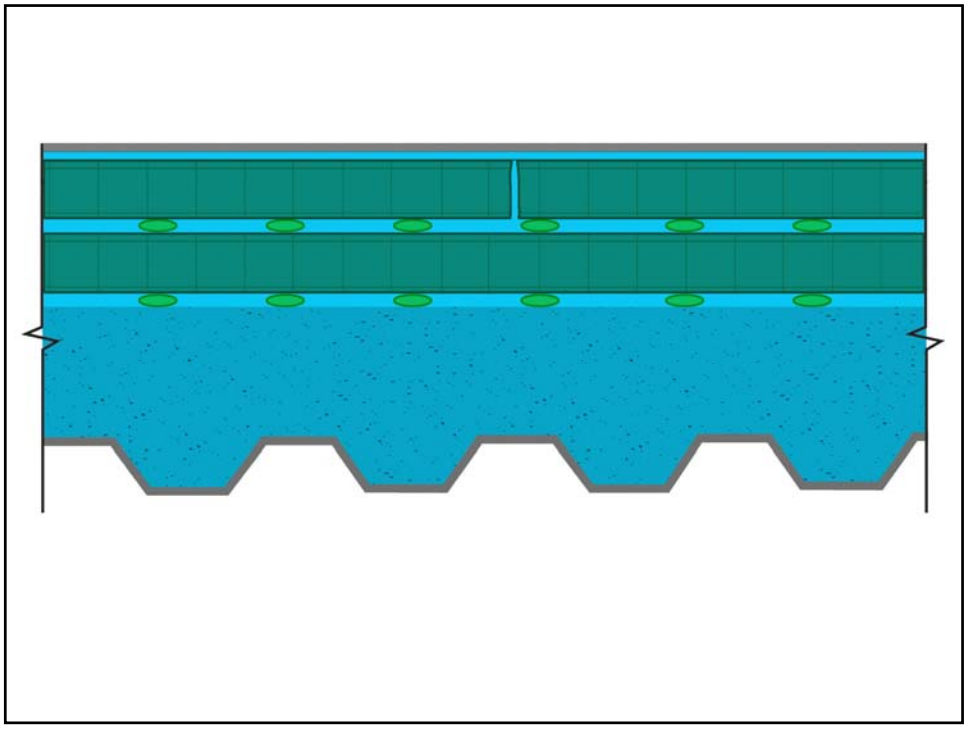
Water Added to and Remaining in Example Concrete Mixes

	Normal Weight Concrete with 0.5% aggregate absorption	Lightweight Concrete with 10% aggregate absorption	Lightweight Concrete with 20% aggregate absorption	Cellular concrete
Total cementitious material (lb/cy)	650	710	710	779
w/cm ratio	0.39	0.43	0.43	0.50
Added batch water (lb/cy)	242	308	308	384
1% fine aggregate absorption (lbs water/cy)	11	13	13	n/a
Coarse aggregate absorption (lb water/cy)	10	73	145	n/a
Total water in batch (lb/cy)	263	394	466	384
Water consumed in hydration reactions (lb/cy)	163	178	178	195
Water remaining after hydration (lb/cy)	100	216	288	189
Water remaining in 6 in. concrete deck (quart/sf)	0.9	1.9	2.6	1.7



Water Remaining in Concrete Roof Decks Exposed One Month

	Normal Weight Concrete (qt/sf) (% of evaporable water)	Lightweight Concrete (20% Aggregate Absorption) (qt/sf) (% of evaporable water)	Cellular Concrete @ 14 days (qt/sf) (% of evaporable water)
Cold-moist climate International Falls, MN	0.7 (80%)	2.2 (87%)	0.5 (33%)
Warm-humid climate Miami, FL	0.7 (80%)	2.2 (87%)	0.6 (35%)
Warm-dry climate Phoenix, AZ	0.6 (70%)	2.1 (83%)	0.3 (15%)

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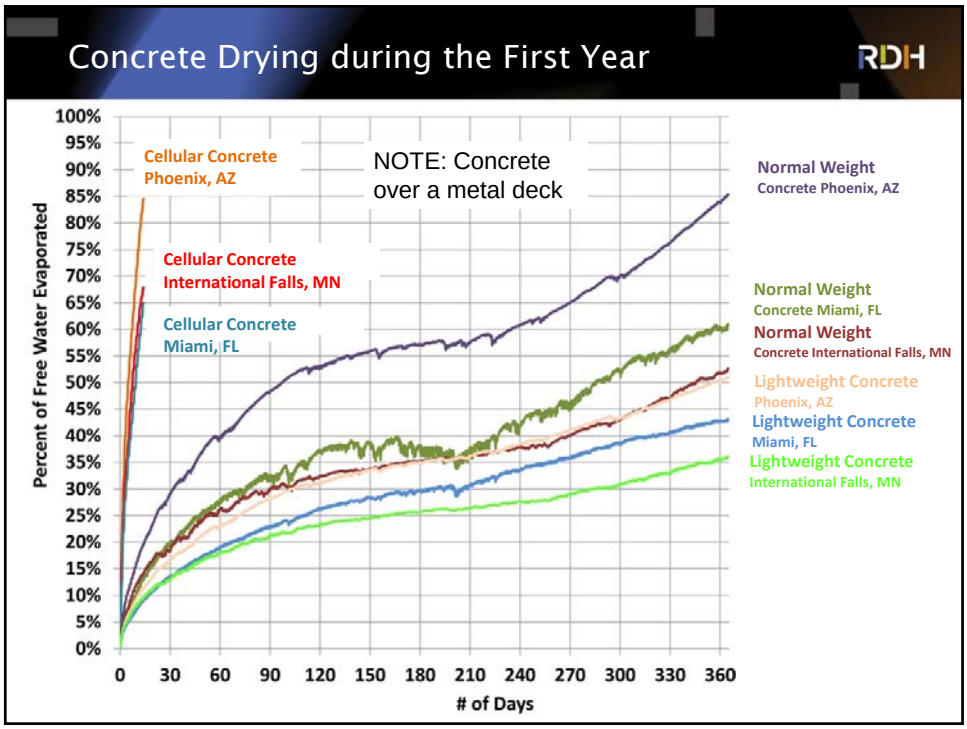
Concrete Drying during the First Year
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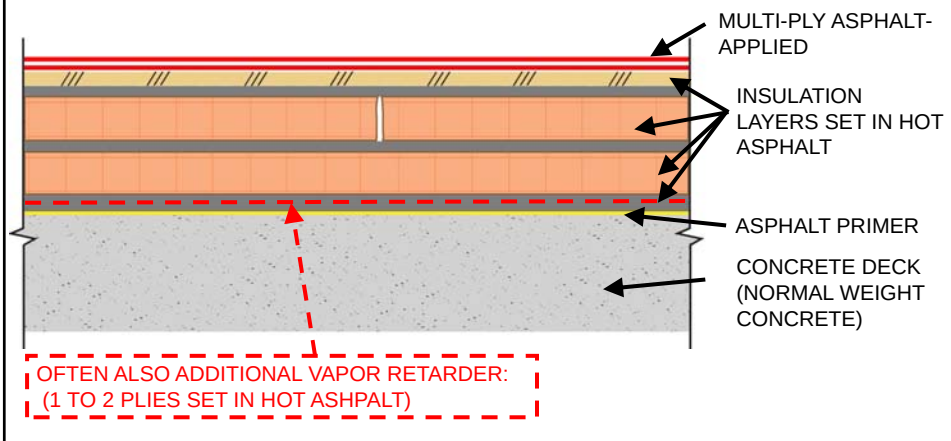
Percent of Free Water Evaporated
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0
30
60
90
120
150
180
210
240
270
300
330
360
# of Days
Cellular Concrete
Phoenix, AZ
NOTE: Concrete
over a metal deck
Cellular Concrete
International Falls, MN
Cellular Concrete
Miami, FL
Normal Weight
Concrete Phoenix, AZ
Normal Weight
Concrete Miami, FL
Normal Weight
Concrete International Falls, MN
Lightweight Concrete
Phoenix, AZ
Lightweight Concrete
Miami, FL
Lightweight Concrete
International Falls, MN

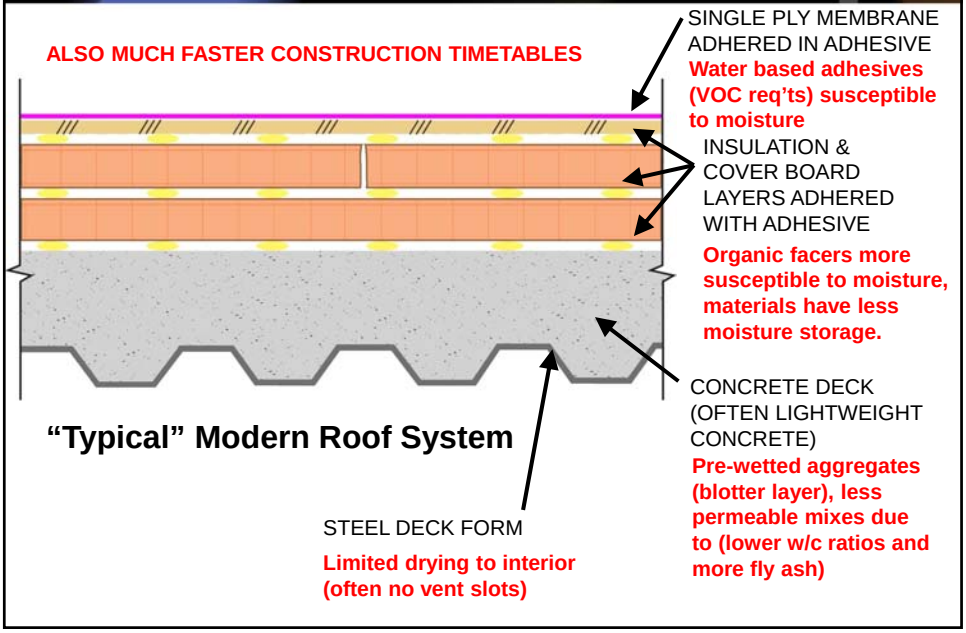
Why More Concrete Moisture Problems Now?



Traditional Roof System

Why More Concrete Moisture Problems Now?

ALSO MUCH FASTER CONSTRUCTION TIMETABLES



"Typical" Modern Roof System

Example Concrete Moisture Related Problems

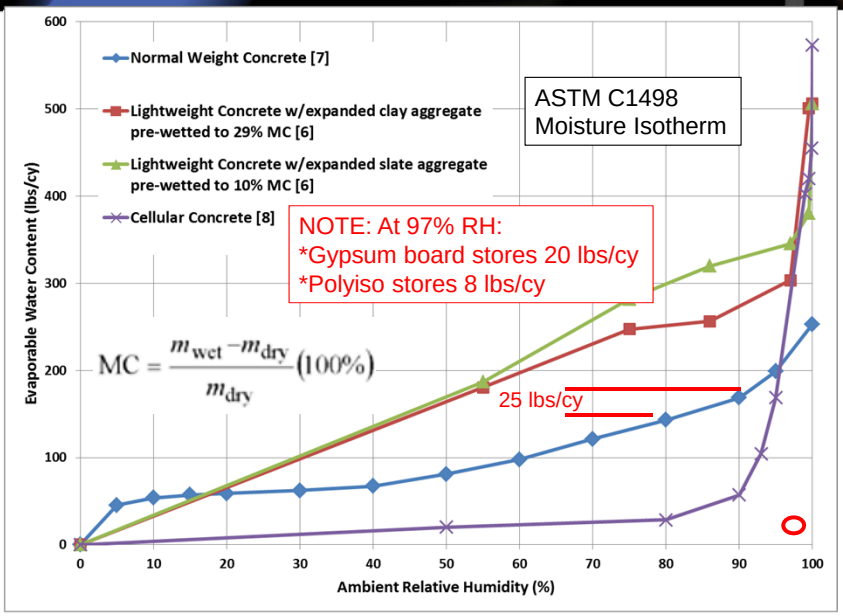
Example Concrete Moisture Related Problems

Example Concrete Moisture Related Problems

"Safe" Moisture Storage Limits of Various Roofing Materials?

- ASHRAE Standard 160: 30 day running ave. surface relative humidity (RH) < 80% (when temp. is b/w 41F and 104F).
- 3% M.C. (85% RH) for 6 in. polyisocynurate: ~0.012 qts. / sf
- 1% M.C. (94% RH) for 1/4 in. gypsum board: ~0.005 qts. / sf
- 5.7% M.C. (90% RH) for 1/2 in. cement board: ~0.080 qts. / sf

Relative Humidity and Moisture Content



Testing for Moisture in Concrete Roof Decks?

→ ASTM F2170: "RH Probe Test"

→ ASTM F1869: "Salt Dome Test"

→ ASTM D4263: "Plastic Sheet Test"

→ Hand held surface meters?

→ Core testing?

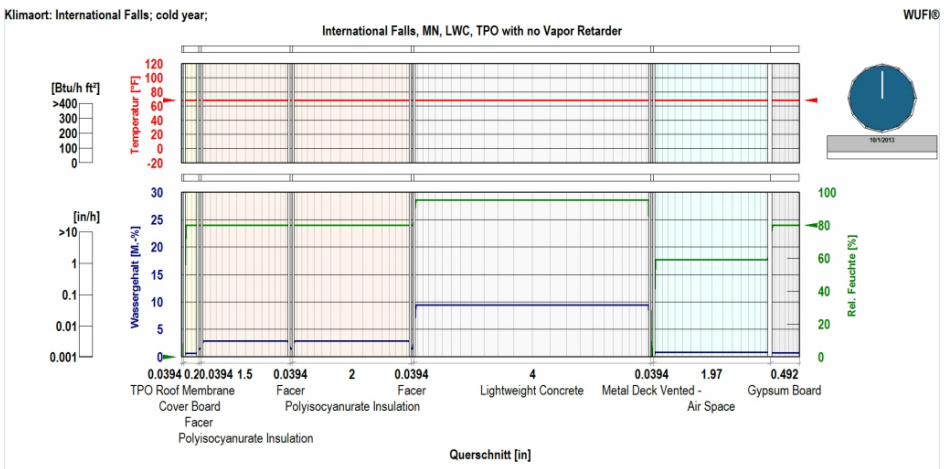
- Above tests are not reliable for roof systems due to:
  - Large temperature fluctuations (both during test and in-service)
  - Solar radiation effects
  - Precipitation
  - **Tests cannot quantify amount of water / moisture in deck**
  - **No way to interpret migration of this moisture without hygrothermal modeling**

Hygrothermal Modeling

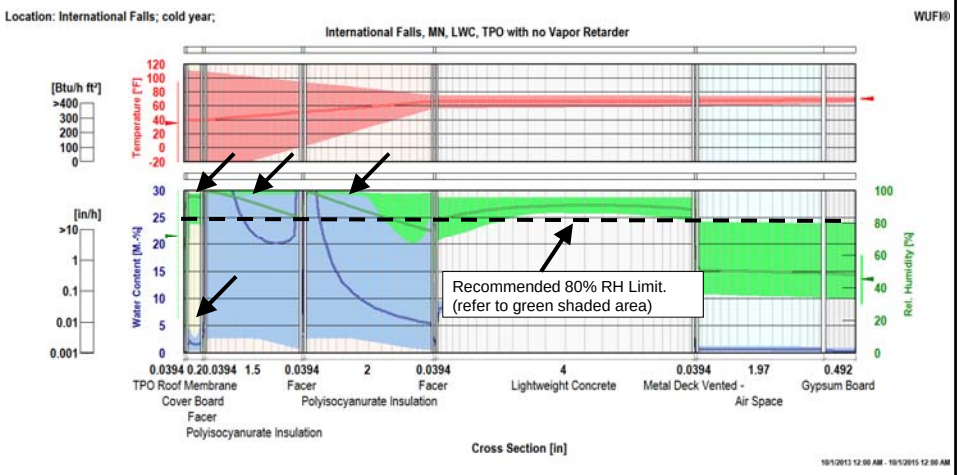
Moisture Migration from Concrete to Roofing System

1. Show a simulation
2. Show results for a cold climate and hot climate with no vapor retarder
3. Show example of a vapor retarder that controls concrete moisture
4. Show design and installation issues with vapor retarders

No Vapor Retarder, Cold Climate – WUFI Film



No Vapor Retarder, Cold Climate



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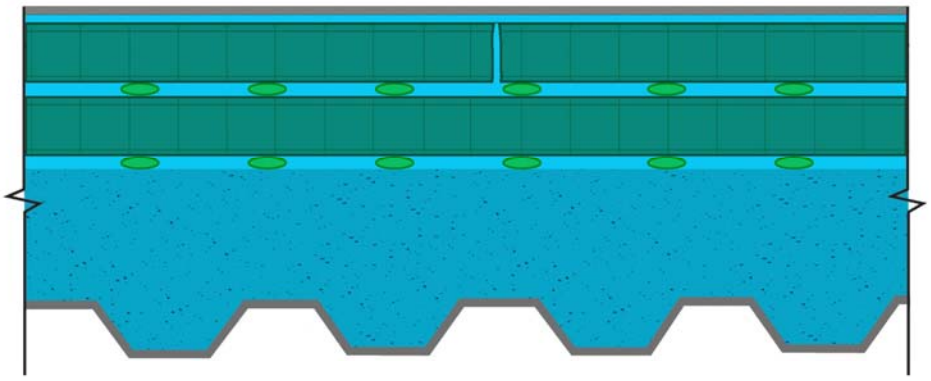

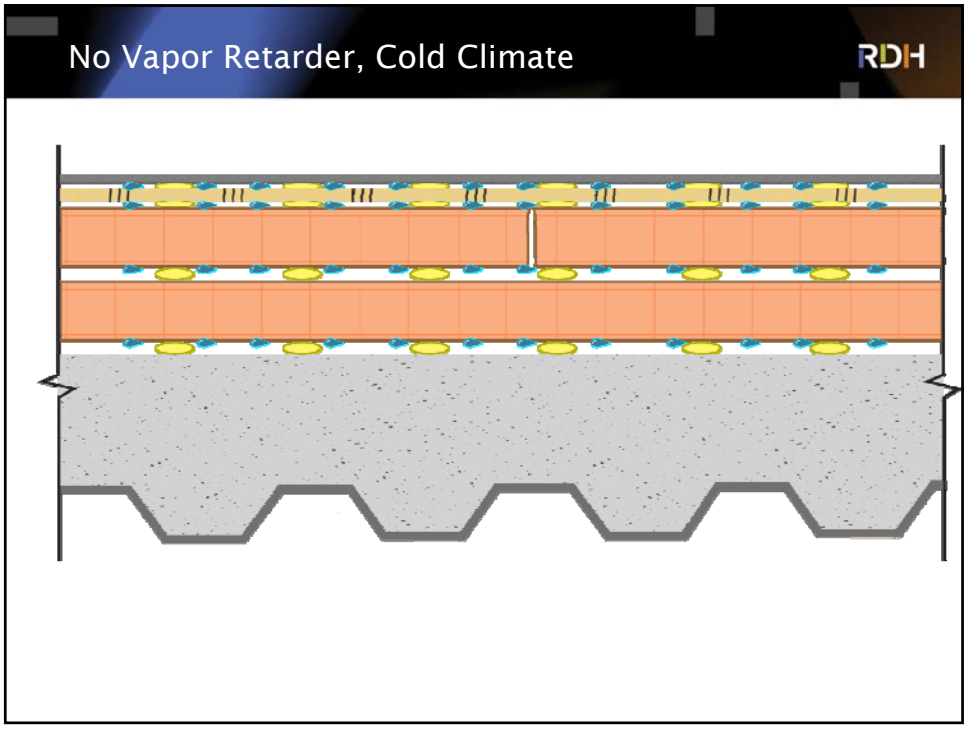
No Vapor Retarder, Cold Climate
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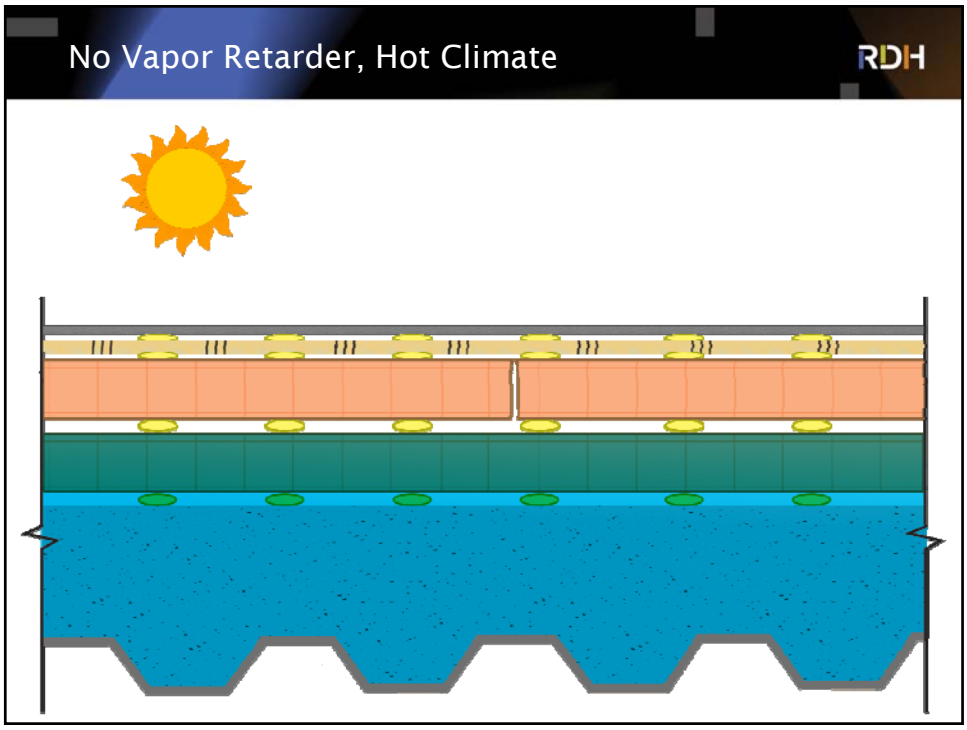
No Vapor Retarder, Hot Climate
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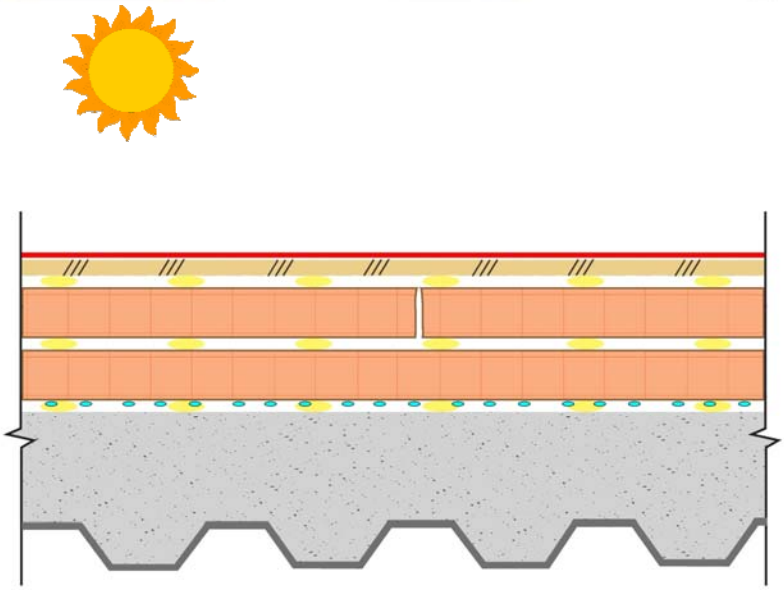
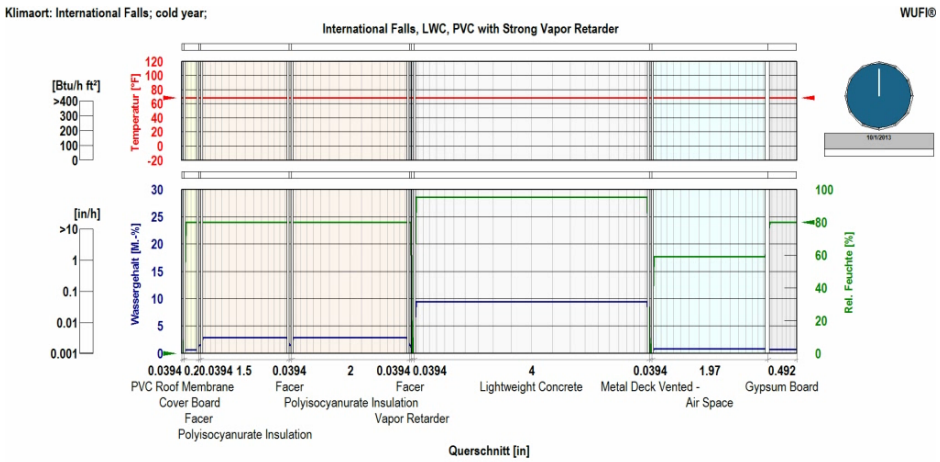
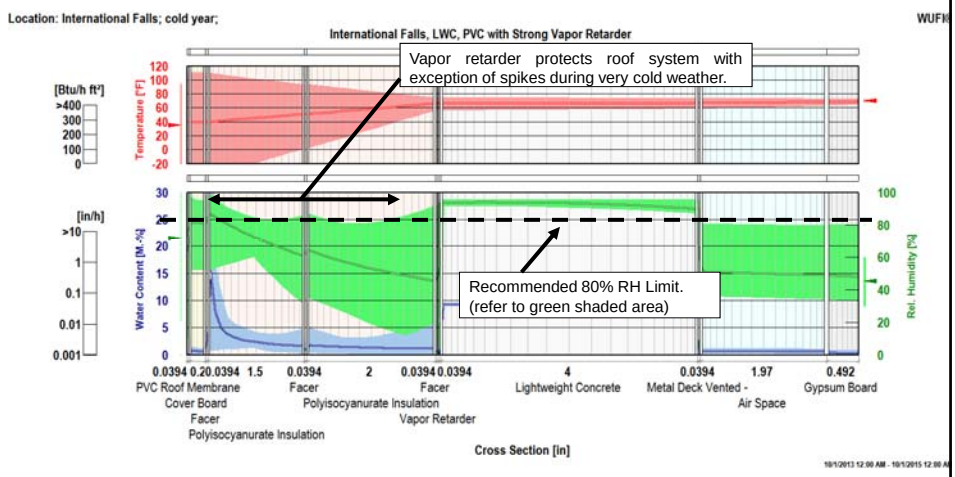
No Vapor Retarder, Hot Climate



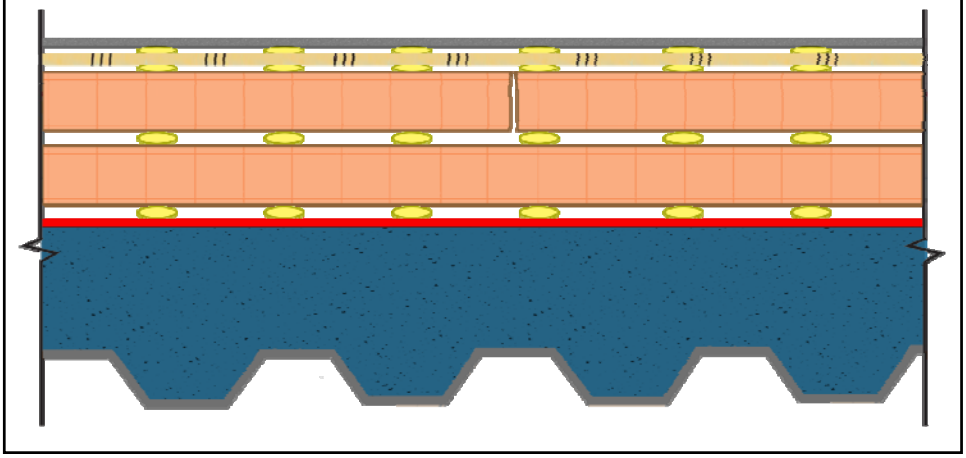
With Vapor Retarder, Cold Climate – WUFI Film



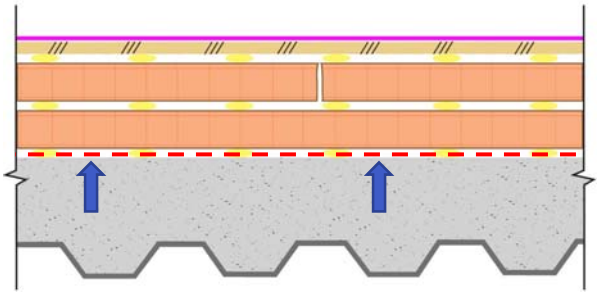
With Vapor Retarder, Cold Climate



With Vapor Retarder, Cold Climate



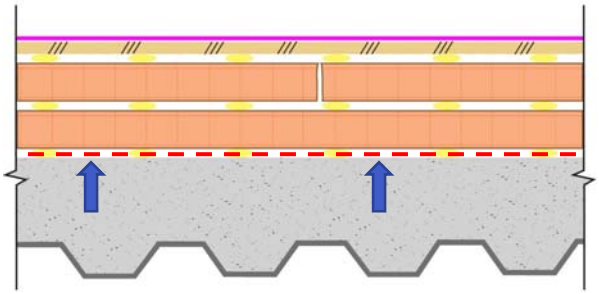
Vapor Retarder (VR) Design & Install Issues



- Bond of VR to concrete (concrete too wet or solar drive)

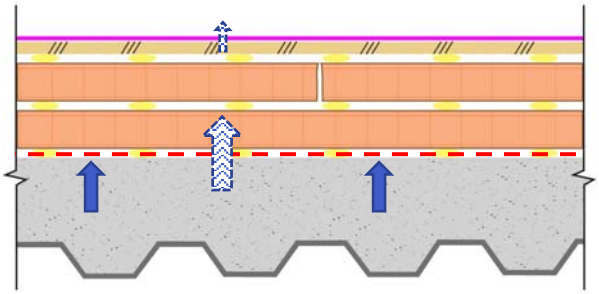
Adhesion Mock-up Testing

Vapor Retarder (VR) Design & Install Issues



- Bond of VR to concrete (concrete too wet or solar drive)
- Bond of Insulation to VR (esp. for adhered VR's)

Vapor Retarder (VR) Design & Install Issues



- Bond of VR to concrete (concrete too wet or solar drive)
- Bond of Insulation to VR (esp. for adhered VR's)
- Permeance of roofing membrane versus VR

Moisture Trapped in Roof Assembly

→ Photo courtesy of SMT (leak detection tape)

New **Draft** Findings from SMT

→ 3 in 5 end of day edge seals leak

→ Wetting during construction still prevalent in wet climates

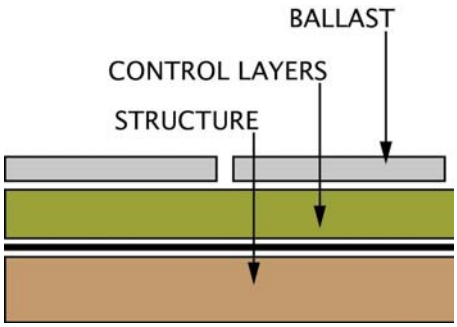
→ When water present insulation adhesives or facers have almost always failed

→ 50% roof drains are over-clamped or have cracking in cast iron

→ Damage during or after construction is still majority of roof failure issues

The 'Perfect' Roof – PMR / IRMA

- → Control layers
  - → Water control - roof membrane
  - → Air control – roof membrane
  - → Vapor control – roof membrane
  - → Thermal control – moisture resistant insulation
- → Membrane directly on sloped structure
- → Insulation above membrane
- → "Finish" – pavers, ballast
- → Why is this 'perfect'?



Take Aways

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1. Concrete roof decks are wet (1 to 2-1/2 quarts of free water per sf in a 6 in. concrete roof deck after hydration).
2. Modern roofing materials are more susceptible to moisture.
3. Least risk design with conventional roof is to incorporate a vapor retarder over concrete roof decks.
4. Best Practice is to specify a protected membrane roof (PMR or IRMA)
5. Hygrothermal modeling and engineering analysis is useful to develop a roof system design or evaluate existing roofs.


Discussion + Questions
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