Vapor Transmission Through Concrete Slabs

Facts and Fictions

by

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2002-2003 Annual Conference

April 12, 2003

Carmel, California

Excessive Moisture Transmission Through Concrete

Popular Issue in Recent Construction Defect Litigation

Is There a Pervasive Problem With Excessive Vapor Transmission Through Concrete?

OR.....

Could it Be……?

- Concrete slab is most expensive single unit in residential construction
  - Defect allegations lead to costly repairs, large damages.
- Aas decision (Economic Loss Rule)
  - Resultant damage to some other component
- SB 800 – Will become even bigger issue!
  - Since start of year illegal to design and supply concrete that transmits vapor (or cracks).

Liquid Transmission vs. Vapor Transmission

- Two different physical phases of water, two completely different physical phenomena.
  - Often interchanged or confused by consultants.
- Liquid transmission:
  - Extremely high pressure (900 fsw).
  - Cracks (requires hydraulic head, slab underwater).
  - Capillarity
- This presentation deals with ***vapor transmission.***

Common Pattern

- Allegation: Excessive vapor transmission through concrete slabs.
- Cause: Concrete is too permeable (porosity often confused with permeability)
- Allegations supported by:
  - Moisture dome testing
  - Vinyl stains
  - Stained tack strips
  - Mold and mildew
  - Efflorescence

Fictions

- Conflict with published data.
  - Alleged rate of vapor transmission higher than published data shows is possible, by several orders of magnitude.
- Conflict with logic, history, or common sense.
  - In many cases source of offending moisture more likely to be above slab than through slab.

Vinyl Stains

- Vinyl stains are often in the immediate vicinity of obvious above-slab source of water:
  - Toilets, showers, washers/dryers, windows, sliders.
- Vinyl stains are often identical or worse on 2nd floor.
- Vinyl stains isolated in field of floor:
  - Vapor is a gas, staining should be pervasive throughout entire floor.
  - Isolated stains suggest material or workmanship problems in flooring material.
    - Confirmed in recent study.

Wet or Stained Tackstrips

- Stains in tackstrips often directly below windows known to leak.
- Vapor passes through slab, enters room air. What would cause it to condense on tackstrip?

Mold and Mildew

- ***Maximum*** possible vapor transmission through slab is a small percentage of vapor generated normally by occupants and normal activities.

- Vapor transmission rates ***through*** slabs and vapor ***generated*** in residences have been studied and results have been published.

Efflorescence

- Normally occurring phenomenon – not a defect.
- Occurs when liquid water comes in contact with cementitious surface.
  - Salts at surface dissolve.
  - When water evaporates, salts are left behind as powdery white material.
  - Generally has no deleterious effect.
- Not related to vapor.
- Vapor does not carry dissolved salts.

Facts

- Brewer PCA study.
- ASTM Manual 18, “Moisture Control in Buildings”.

Definitive Work on Vapor Transmission

The Brewer PCA tests (1965)

Moisture Migration — Concrete Slab-on-Ground Construction

By
H. W. Brewer, Development Engineer
Products and Applications Development Section
Research and Development Laboratories
Portland Cement Association

SYNOPSIS

Concrete slab-on-ground has become a widely used method of construction. Moisture migration from such slabs is of importance primarily because of its effect on certain types of floor coverings.

This study reports data on 101 specimens cast from 29 mixes covering a wide range of concrete quality. The program included exposure conditions varying from water-in-contact to drying only, as well as the effect of admixtures, vapor barriers, and gravel capillary breaks. Several different test procedures were studied in the course of the investigation.

Good correlation was found between moisture migration and water—cement ratio [w/c]. Flow increasing directly with w/c. Admixtures had little effect on moisture migration measured by these methods. Vapor barriers and gravel capillary breaks produced little or no change in the measured flow at early ages, but reduced the flow at later ages.

The superior resistance to moisture migration of good quality concrete, relative to that of lower quality concrete, was amply demonstrated in this study regardless of time or type of exposure. Analysis of the data established that outflow measurements rather than inflow measurements properly evaluate moisture migration at early ages. The outflow measurements indicated that rate of moisture loss at early ages is 4 to 10 times the flow through the concrete.

INTRODUCTION AND BACKGROUND

Initially the extensive use of concrete slab-on-ground as a method of construction was employed in warm and dry areas, and asphalt tile was the common floor covering. Later, less permeable coverings were adopted and slabs were also constructed in areas with less favorable soil and climatic conditions. These circumstances have placed greater emphasis on the need for information dealing with moisture migration through concrete slabs.

The keen interest and the need for technical information regarding concrete slab-on-ground is evidenced by five reports on the subject issued since 1955 by the National Academy of Sciences—National Research Council through the Building Research Advisory Board.

"Slab-on-Ground Construction for Residences," NAS-NRC Publication 385 (June 1955),[11]* discusses site preparation, need for capillary breaks and vapor barriers, slab design, and insulation. The report terminates with 10 research recommendations indicating the need for much technical information.

"Vapor Barrier Materials for Use with Slab-on-Ground Construction," NAS-NRC Publication 445 (May 1956),[12] is a report describing required properties of vapor barriers and pertinent test methods to evaluate these properties.

"Effectiveness of Concrete Admixtures in Controlling Transmission of Moisture Through Slab-on-Ground," NAS-NRC Publication 596 (July 1958),[13] describes a test procedure to evaluate the effectiveness of admixtures on moisture control. The committee knew of no admixture that would be sufficiently effective to replace either a vapor barrier or granular base where such protection was needed.

"Design Criteria for Residential Slabs-on-Ground," NAS-NRC Publication 657 (March 1959),[14] recommends a procedure for analysis of structural slabs. The committee delineated four major types of slabs and recommended particular types for various combinations of site and climatic conditions.

"Protection from Moisture for Slab-on-Ground Construction and Habitable Spaces Below Grade," NAS-NRC Publication 707 (February 1959),[15] describes site preparation and also use of capillary breaks, vapor barriers, and good quality concrete for controlling moisture. It also includes recommendations regarding insulation and finish floor coverings.

The purpose of all of these BRAB reports was to provide information that would be helpful to the Federal Housing Administration in establishing Minimum Property Standards on this subject and in defining needed research activities.

Although there are numerous references in the literature to moisture migration through construction materials, few of these are directly applicable to concrete. One of the most comprehensive investigations is that made by Professor G. E. Lund at the University of Minnesota for the U.S. Navy Bureau of Yards and Docks.[16] The study included three different types of concrete over six different types of soil. Two admixtures, two surface coatings, and a moisture barrier were studied. This investigation showed the advantage of using high quality concrete and of providing a capillary break beneath the slab. None of the admixtures or surface treatments was beneficial. Heavy asphalt-impregnated and laminated felt was a very effective moisture barrier.

A study by the Forest Products Laboratory for the Housing and Home Finance Agency[17] included the use of capillary breaks and vapor barriers beneath the slab. However, only one specimen was provided for each of six test conditions, and this fact, together with some apparent inconsistencies, seriously limits the usefulness of the data.

Kreczmik and Swenson[18] used both water and water vapor test procedures to evaluate waterproofing additives in lean (1:6 and 1:7) portland cement mortars. Th found that an integral bituminous em sion was an effective waterproofing ma rial, when tested by the water vapor pro dure, and that ammonium stearate w effective in the leaner mortar. When tes under saturated conditions with 32 cen meters of water on the slab, none of t waterproofing additives was beneficial.

Powers, Copeland, Hayes, and Mann have discussed the permeability of cem paste and have shown the advantage of l water—cement ratio and continued m curing in reducing permeability.

A recent article by Griffin and Henr is concerned primarily with salt contami tion of concrete, but concludes that wa vapor transmission increases with an crease in water—cement ratio.

Tests and experience have shown t difficulties normally encountered with c crete floors on grade can be largely eli nated by adherence to good construc practice. The recommendations of Building Research Advisory Board as gi in reference 5 provide good advice. Care selection of site, provision for proper dra age, and observance of the fundamen rules for making concrete will elimin most of the problems. However, the f that concrete contains water which is l upon drying, and that under certain c ditions some water will pass through poses a problem that can be only partia alleviated by good construction procedur

The concern over moisture migrati through or from a concrete slab is not w respect to its effect on the slab, but its eff on resilient tile, wood or other floori tuning of metal, etc. Retention of water passage of water through concrete is g erally not detrimental to the concrete. T concrete slab should be moist cured for s eral days after casting, and strength a impermeability of the concrete are b further improved by longer curing. On other hand, the concrete surface should relatively dry prior to installation of m floor coverings. Under usual construct practice, floor coverings are installed wi in a few weeks after the concrete slab h been cast, entrapping much of the origi mix water in the concrete, which later c tributes to buckling of wood floors a affects adversely the adhesives used w some of the resilient tile. Under these c ditions, the moisture outflow from the s

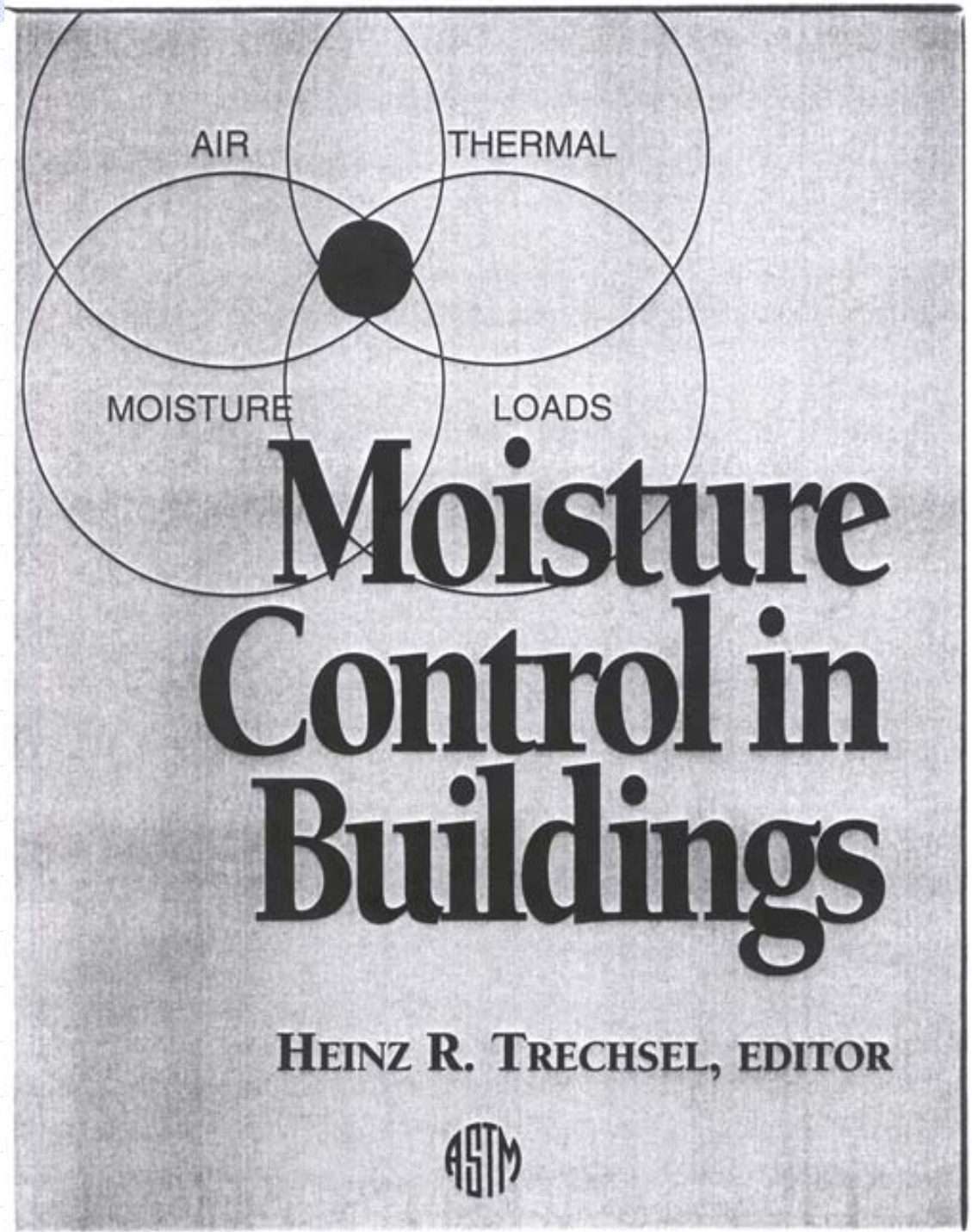
*Numbers in parentheses refer to references at end of paper.

Brewer Tests

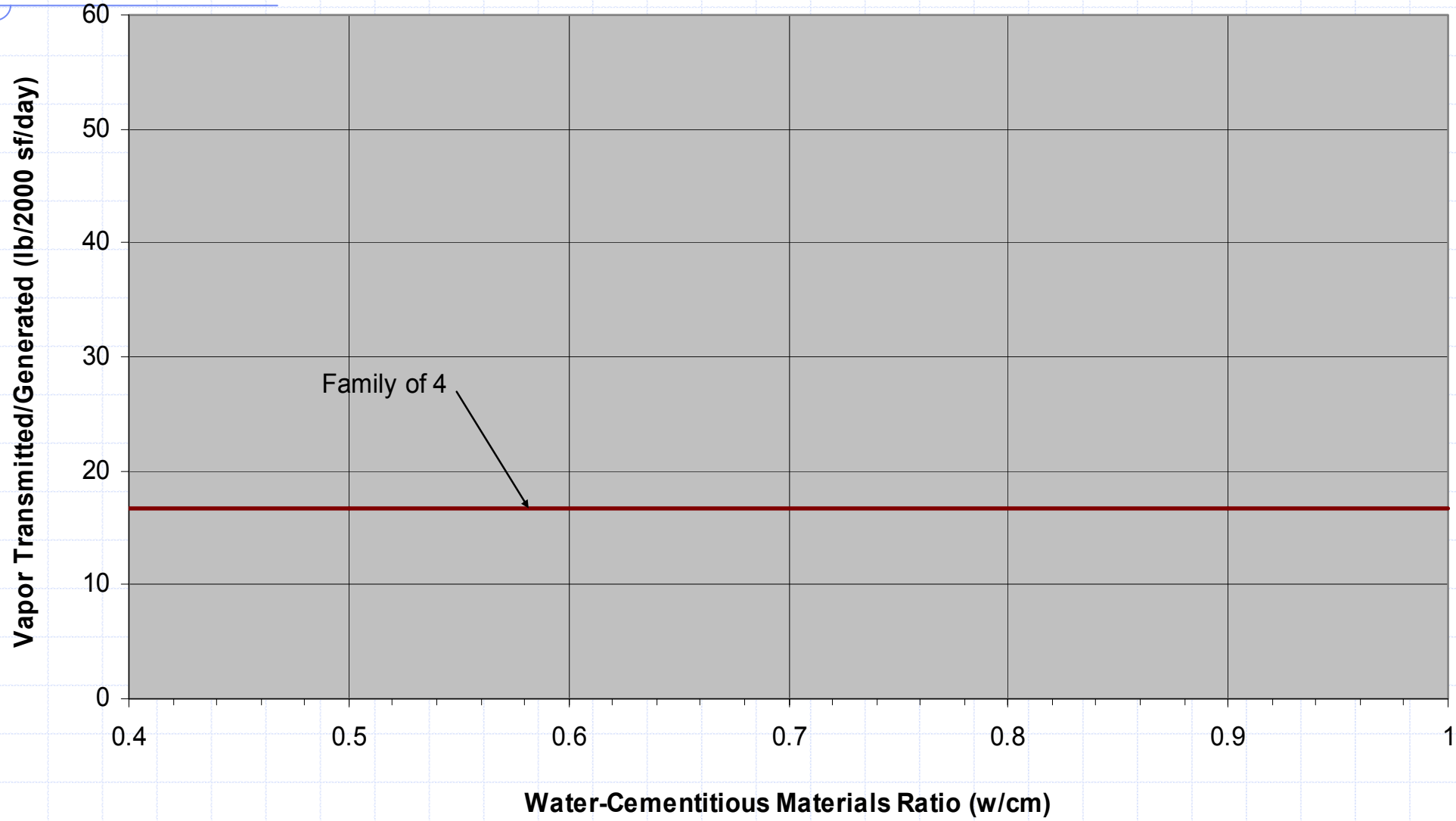
- Isolates vapor transmission and vapor emission.
- Quantifies rates of vapor transmissions and emissions as a function of:
  - Water/cement ratio.
  - Exposure.
    - Direct water contact, direct vapor contact.
    - Subgrade materials (sand, vapor retarders).

ASTM Manual 18

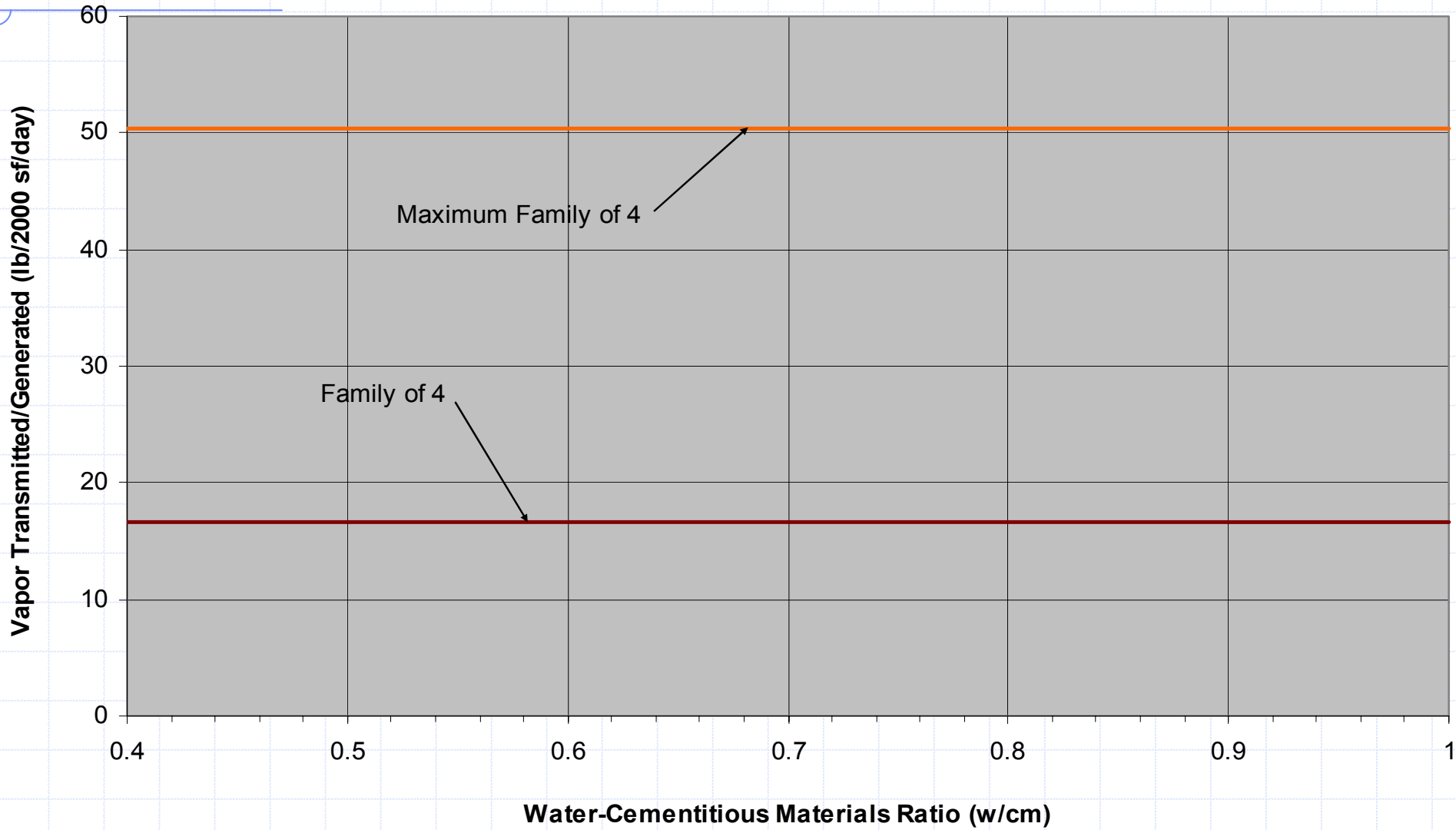
"Moisture Sources"
p.179
Vapor generated within building envelope



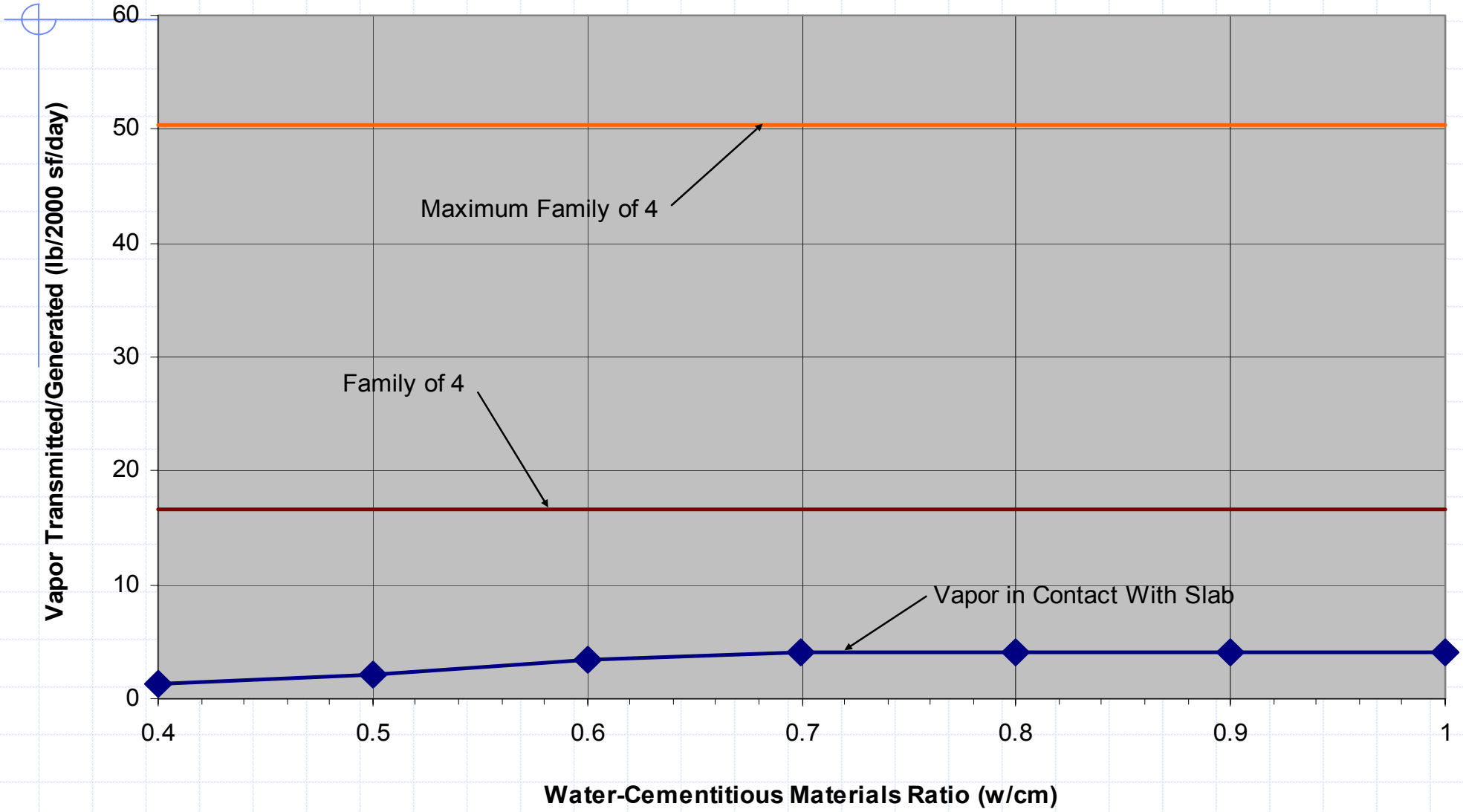
Vapor Generated in Home ("Moisture Control in Buildings", ASTM MNL 18)



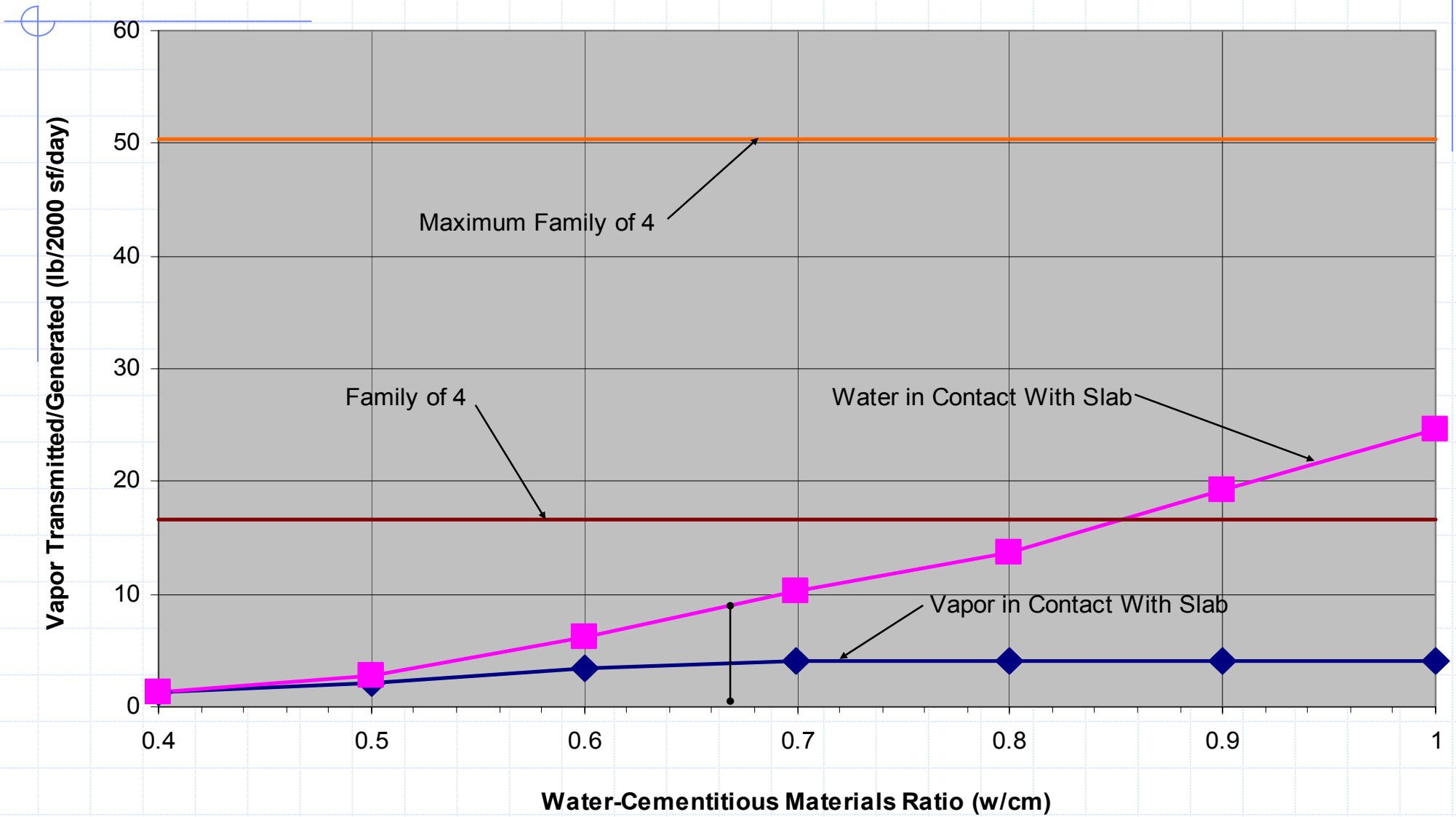
Vapor Generated in Home (ASTM MNL 18)



Vapor Transmitted Through Slab (Brewer) vs. Vapor Generated in Home (ASTM)



Vapor Transmitted Through Slab (Brewer) vs. Vapor Generated in Home (ASTM)



Vapor Retarders (Visqueen)

- Usage is geographic and historical.
  - Commonly used in California.
  - Normally not used in Arizona.
  - Both climates semi-arid, no significant differences in residential moisture problems.
- Lack of continuity often cited as cause of excessive vapor transmission through slab.
  - Pinholes, punctures, laps

Effects of Vapor Retarders

(from Brewer Series 3)

Test Condition	Moisture Outflow (lb/1000sf/24hr)		Moisture Transmission (lb/1000sf/24hr)		Reduction in Moisture Transmission (lb/1000sf/24hr)		Reduction in Moisture Transmission (%)	
	w/cm		w/cm		w/cm		w/cm	
	0.5	0.7	0.5	0.7	0.5	0.7	0.5	0.7
Water in contact with concrete	2.5	6.52	1.5	5.15				
Water **vapor in contact** with concrete	2.26	3.43	1.26	2.06				
Water in contact with 4-mil polyethylene	1.54	4.02	0.54	2.65	0.96	2.50	64%	49%
Water in contact with 32-mil ABS plastic	1.10	2.87	0.10	1.50	1.40	3.65	93%	71%
Water **vapor in contact** with 4-mil polyethylene	1.39	2.11	0.39	0.74	0.87	1.32	69%	64%
Water **vapor in contact** with 32-mil ABS plastic	0.99	1.51	0.00	0.14	1.26	1.92	100%	93%
Drying only	1.00	1.37						

Moisture Dome Tests

Moisture Dome Test Developed 40+ Years Ago

- By the "Rubber Manufacturer's Association"
- Original Test Purpose:
  - To determine if a concrete slab is dry enough to permit the installation of resilient flooring materials

ASTM Detailed Test Protocols

- Two published ASTM test protocols for the moisture dome test:
  - ASTM E 1907 – published in 1997.
  - ASTM F 1869 – published in 1998.
- Significant differences between the two.
  - Number of tests (500sf or 1000sf?).
  - Delay time after cleaning slab (24 or 48 hours?).
  - Recording of temperature and relative humidity.
  - Area under dome (deduct area of container?).

Two ASTM “Standards”?

- Why two?
- Why do they have significant differences?
- Appears that flooring industry cannot decide how to run these tests.

Test Program Initiated in 1998

(Peters v. Brighton case)

- To study the physics of moisture dome tests <u>on mature slabs</u>:
  - Is the test reproducible?
  - How are test results affected by temperature and relative humidity?
  - What are the sources of moisture measured in the test?
  - Can the test be used to measure concrete permeability or vapor transmission through concrete slabs-on-ground?

Started With Literature Search

- Published articles.
- Internet.
- Personal communications with flooring consultants, concrete material specialists, scientists specializing in permeability testing, etc.

No Published Standards Exist…..

- Which relate the results of a moisture dome test:
  - To acceptable levels of vapor emission entering into a residential space by any path.

No Published Standards Exist…..

- Which relate the results of a moisture dome test:
  - To concrete porosity or permeability.

There Are Recommendations From Flooring Companies…

- They relate the results of moisture dome tests to the installation of flooring materials (3# for vinyl, 5# for carpet, etc.).
- These recommendations are arbitrary and are not based upon any scientific study or published work. They are established and disseminated by flooring companies.
- They are controversial for their intended purpose even within the flooring industry.

From the Flooring Industry

- From "FLOORINGINSTALLER.com" message board: http://www.flooringinstaller.com/ubb/Forum14/html/000081.html

- Robert Higgins, SINAK Corp, *"Statistically speaking, approximately 80% of the concrete floor slabs in California have [moisture dome test] values in the range of 5-8#. This is approximately 1.5-2.5 times higher than the allowable maximum by manufacturers, yet, only a SMALL percentage of these floors prove to be problematic."*

More From FLOORINGINDUSTRY.com

- *"There is no direct correlation between moisture emissions and floor failures."*

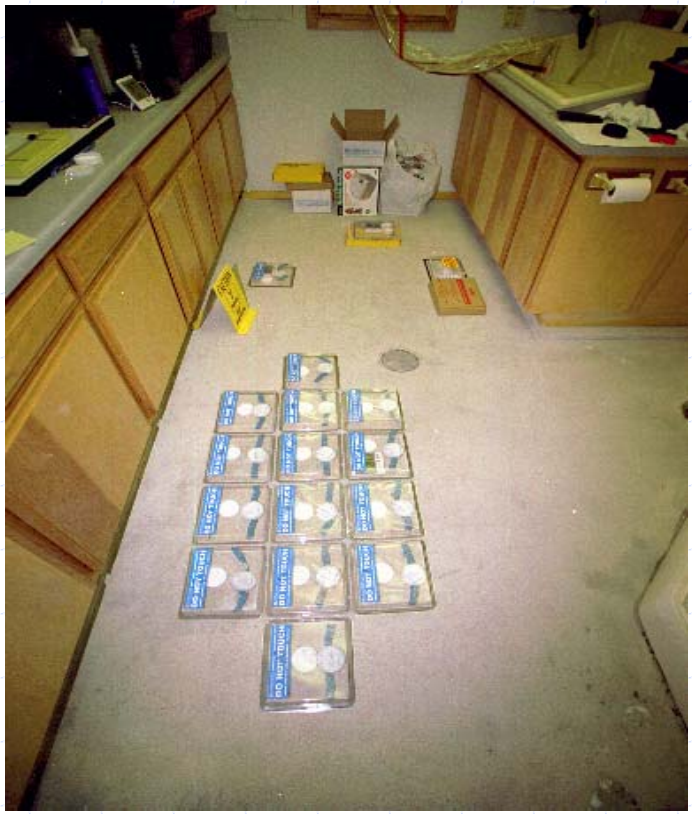
Test Program Description

- Duration 16 months starting in 1998.
- 101 individual dome tests from 4 test kit suppliers.
- 6 “Phases”, each an experiment to study a different aspect of the dome test.
- Tests run on 3 unique “surfaces” in a typical wood-framed Southern California residence.
- T & RH accurately controlled and measured in room, domes, concrete, soil.

Instrumentation Inside Dome

Surface #1

- 4” SOG 10 years old.
  - Dry sandy native soils (3% m.c.)
  - No Visqueen.
  - Successful resilient tile floor installation for 8 years.
  - Tile removed, concrete surface bead-blasted (48 hrs before test).

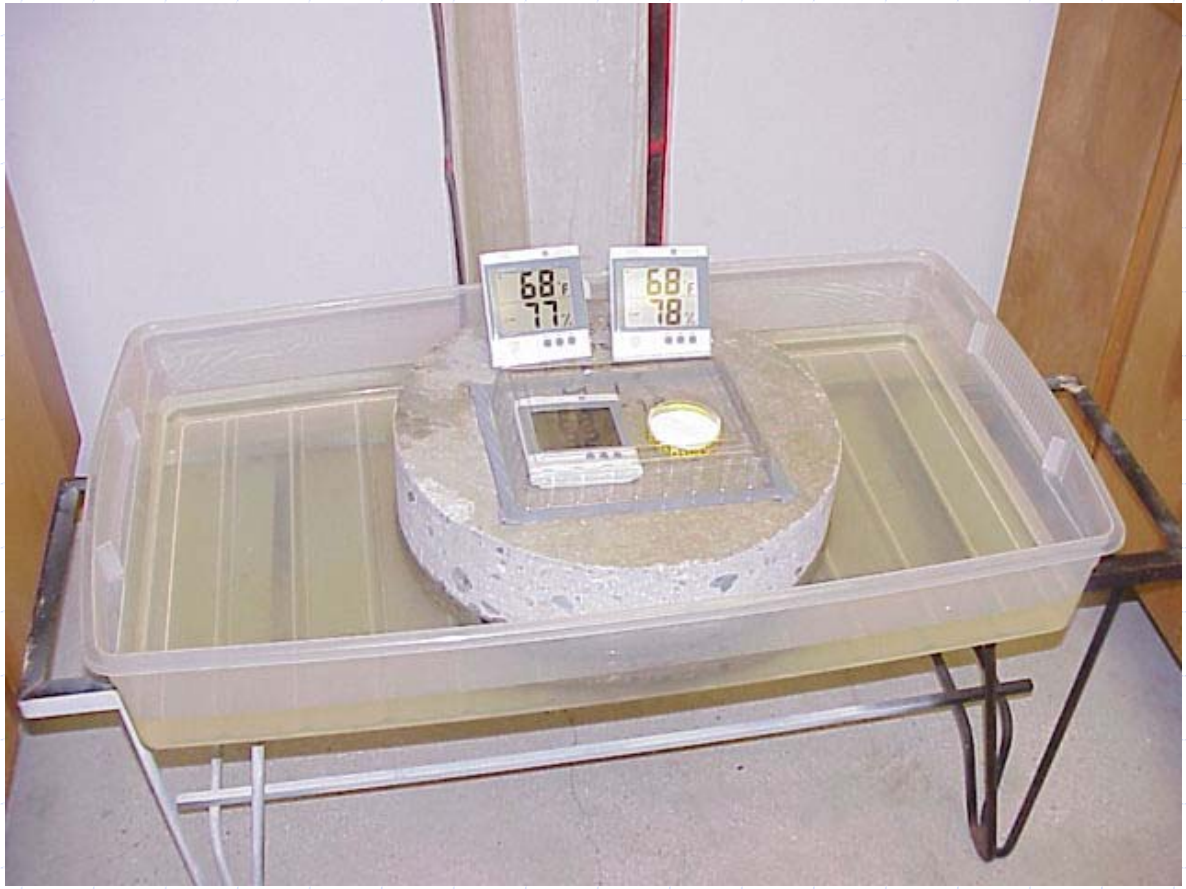


Surface #2

- ½” Plexiglas sheet

“Surface” #3

- Bottom of Core submerged in water for 6 months.



Test Cluster Layout Surface #1

15

16

17

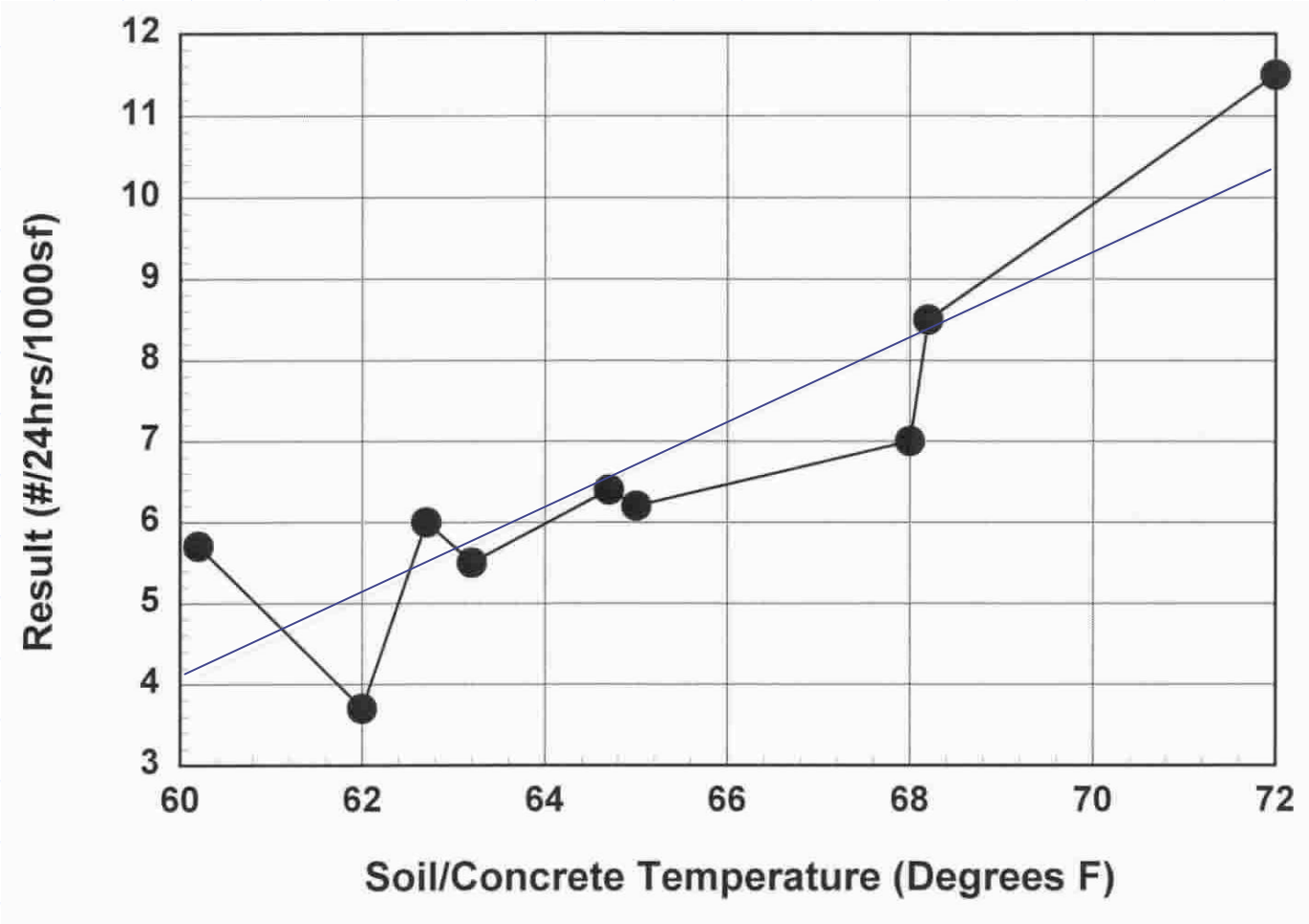
Conclusion 1 - Reproducibility

- Test is not scientifically reproducible.
  - Test results commonly vary by more than 100% under identical conditions (High/Low=2).
- Major reasons:
  - Variability in grind of CaCl crystals.
  - Variability in floor surface preparation and/or condition.

Conclusion 2 – Environmental Conditions

- Test results vary approximately 30% within the range of air temperatures and relative humidities recommended by ASTM test protocol.
  - Recording of temperature and relative humidity rarely done by forensic consultants.
  - No way to judge effects of temperature & relative humidity.
- Most significant environmental factor affecting test results was temperature at soil/concrete interface.

Conclusion 2 - Effect of Soil/Concrete Temperature

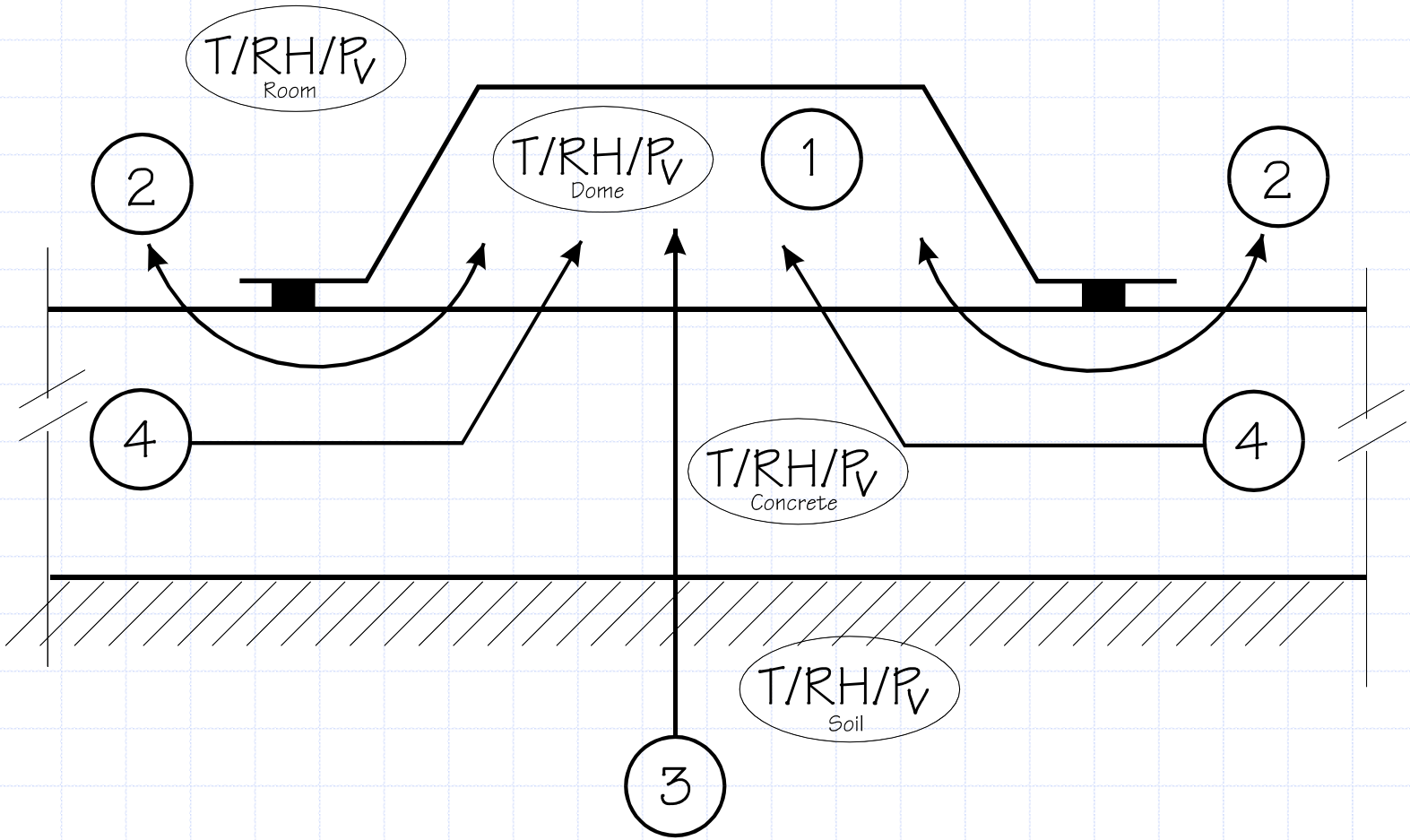


- Each point is average of tests run at same time
- All tests made at same location on slab (domes touching)

Conclusion 3 – Vapor Sources

- Four sources of vapor measured in dome test:
  - Vapor above slab trapped in dome air.
  - Vapor above slab passing under seal.
  - Vapor transmitted through slab.
  - Vapor in equilibrium in pores of mature concrete and activated by test itself.

Conclusion 3



Conclusion 4 – Concrete Properties

- Test cannot be used as a measure of concrete permeability.
  - No standard exists relating results of dome tests to any concrete material property.
  - Most of vapor measured in dome test is not transmitted through slab.
  - Difference in vapor transmission between high and low permeability concretes too small to be detected by dome test (example to follow).

Conclusion 5 – Vapor Transmission

- Test cannot be used as a measure of vapor transmission into residential spaces:
  - No standard for this by any path, even if it could be quantified by the dome test.
  - Most of vapor measured in dome test is not transmitted through slab.
  - Vapor transmitted through slab cannot be isolated from other 3 sources (although it can be reasonably maximized by Brewer tests).

Source 1 – Vapor Trapped in Dome

- 0.5# to 1.25# (confirmed by others).
- Depends on temperature and relative humidity above slab.
- May be influenced by moisture drawn out of substrate material (Plexiglas) and dome plastic.

Source 2 – Above-Slab

- Vapor passing under seal or under surface pores of concrete under seal.
  - Either into or out of dome.
  - Cannot be isolated from other sources.
  - Contribution is small.

Source 3 – Vapor Transmitted Through Slab (from Brewer)

- Can be maximized but not isolated. For 4" slab, w/c ratio=1.0, directly exposed to vapor:
  - Maximum vapor transmission possible is 2.05 lb/24hr/1000sf (lower for lower w/c ratios).
- Extreme exposure - water surface was immediately below slab and no soil or vapor retarder (directly exposed to vapor).
- Moisture dome test values higher than 2.05 lb are measuring vapor that did not pass through slab.

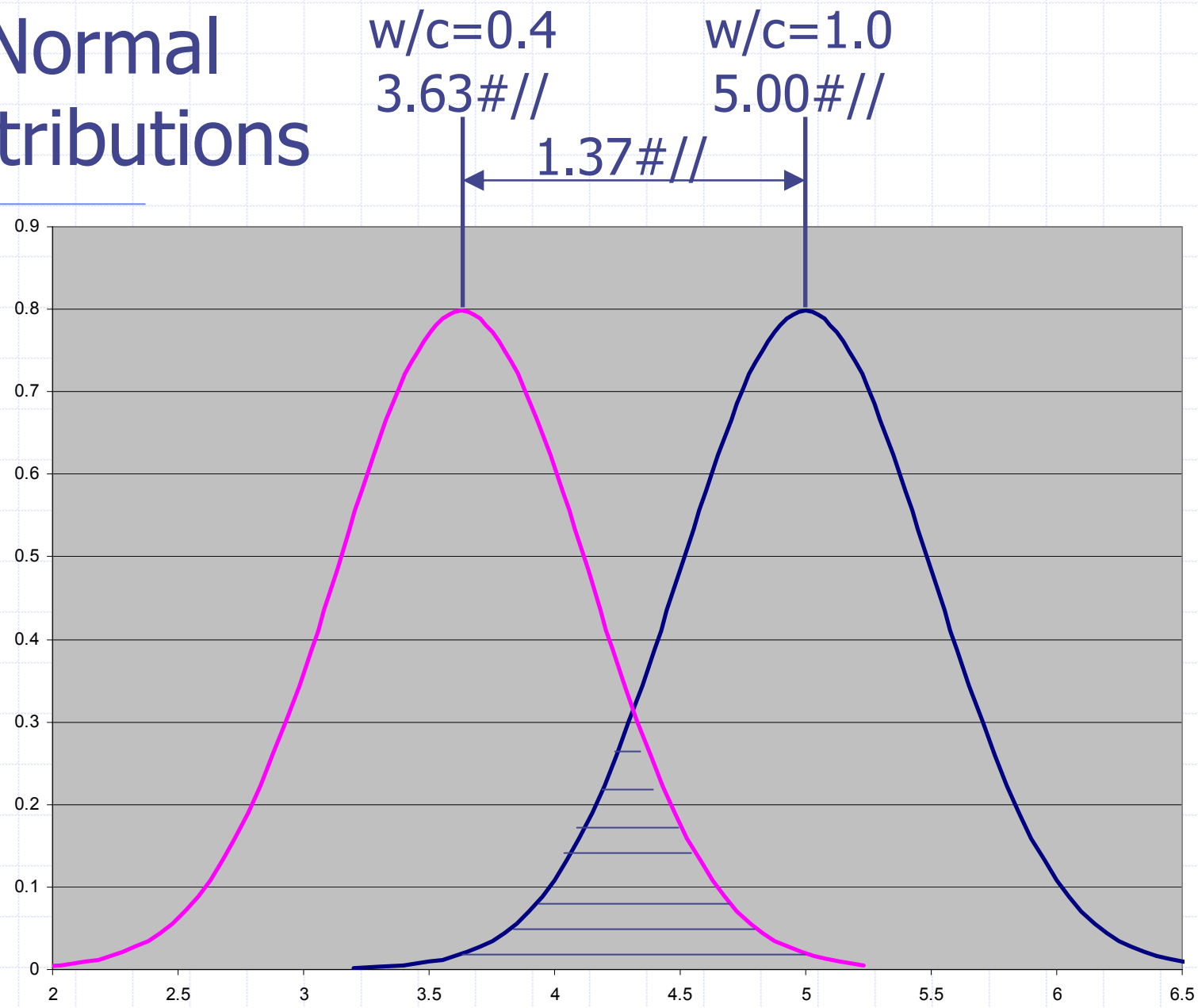
Source 4 – Largest Consistently Available Source of Water

- From water in equilibrium in pores of concrete (normally about 4% by weight in mature residential slabs).
- Activated by test itself. Would remain in concrete without a significant change in environmental conditions (like the test).
- Water under dome:
  - Total – Test result 667#/1000sf/24hr
  - Top ¼" – Test result 42#/1000sf/24hr

Dome Test Variability

- Dome test cannot detect the difference between high and low permeability concretes.

Normal Distributions



Moisture Dome Testing Excluded in So. California Case

- Defendant's Kelly-Fry "junk science" motion granted in Spitz v. Brighton/Brannon, 160 dome tests excluded as evidence.
- Judge said test is not generally accepted in relevant scientific community for purposes used.
  - Relevant scientific community includes those involved in design, construction, investigation of concrete, NOT the flooring industry.
- Judge also cited violations in ASTM test protocols.
- Similar motions presently filed on many more cases.

The End

Thank You!

Full text of paper with all results is on
www.kenbondy.com