"WHITE PAPER"

<u>Concrete In-situ Relative Humidity Testing – Friend or Foe?</u>

Moisture in Concrete, Concrete Drying & Vapor Retarders

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George Donnelly, principal
George Donnelly Testing & Inspections
1 Curso Lane
Hot Springs Village, AR 71909
(501) 915-0626

Moisture related floor covering system failures continue at an unacceptable rate. Distress and failure claims are not limited to slab-on-ground construction, moisture related claims occur when floor coverings are installed over suspended concrete slabs as well. All affected parties understand that moisture related floor covering system distress and failure is an extremely costly occurrence. Whether the cost is in dollars, reputation or good will, failures are costly. It is long past time that such failure should be widespread. Concrete dryness testing must be properly performed, accurately interpreted and acted on with a ferocious desire to prevent failure. Modern test methods were intended to prevent distress and failure by allowing parties to quantifiably test concrete dryness, interpret data and make informed decisions before floor coverings or coatings were installed. Too often data is incomplete, tests were performed improperly and/or the value of test data was mistakenly interpreted. Concrete in-situ relative humidity testing has become the most widely used test method in the United States and arguably it is now the most abused and misinterpreted test we see in the marketplace. Is this test a friend or foe?

This paper is intended to consider the value associated with concrete in-situ relative humidity testing under normal field conditions. Further, this paper contains background information related to concrete drying and the passage of moisture from concrete. Following the protocol of a standard test method is a good thing. Understanding why a test is performed and what the results represent facilitates making an educated, informed decision. Without doubt, since the first floor covering installed over concrete exhibited distress, there have been numerous studies with hundreds of pages of text published. I have chosen five (5) studies dating to 1954 to help the reader understand concrete dryness testing history. The following pages contain excerpts these five (5) studies with limited interpretations, along with field and lab experiences of the author, and opinions based on discussion or consultation with other professionals performing concrete dryness testing.

Concrete In-Situ Relative Humidity testing is being regularly performed in new and old concrete across the United States and elsewhere. The American Society for Testing and Materials aka ASTM, committee F.06 on Resilient Flooring, first published a U.S. standard test method for the use of in-situ probes in concrete in 2002. The ASTM standard is entitled "Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using in situ Probes" and carries the ASTM designation F2170. There has already been a great deal published by others regarding the data generated by this test method. It is this author's opinion that even data generated under the best practices of ASTM F2170 is often misunderstood or misinterpreted to the detriment floor covering projects.

It is this author's additional opinion that exclusive use of in-situ relative humidity test data is too often misleading and may either result in latent floor system failure or cause concrete to be "sealed" when such a cost and treatment are unnecessary. Test data should never be ignored, but understanding the factors that affect test data should be a requirement of anyone making judgements or decisions related to a data set.

Relevant History

1954 -

Concrete moisture emission, moisture transmission and concrete drying studies have been performed and published in the United Sates since at least 1954. The earliest report in the author's library is entitled "Moisture Migration From The Ground". This 1954 study and report also known as "Housing Research paper 28" was commissioned by the U.S. Housing and Home Finance Agency and based on testing performed at the U.S. Forest Products Laboratory, Madison, Wisconsin. There is not enough room in this paper to discuss in detail all of the study's parameters and findings, but a few items are worthy of note. The report opens with the statement:

"Changes and new developments in building construction during the past few decades have brought about an increasing need for control of moisture which often migrates upward from the ground".

The paper describes the effect of vapor pressure differentials associated with temperature and humidity levels above, internal to and beneath a concrete floor slab as the motive force behind moisture vapor movement. The paper states:

"***Variables in temperature and in humidity conditions, in the ground beneath the slab and in the room above it, also, no doubt, would have an effect on this moisture migration."***

In the paper's discussion of the significance of collected data we see:

"***The one method, on which most authorities are in agreement, of preventing moisture migration through a concrete slab-on-ground floor is the use of a membrane that is impermeable to the passage of both liquid and water vapor"…. "Such a barrier would have to be durable for the life of the building"… "it should be an exceptionally good vapor barrier approaching the effectiveness of metal sheet, unless other measures are taken to prevent moisture from reaching the bottom of the slab".***

While modern sub-slab vapor retarding membranes should not be compared to sheet metal, they should meet very strict permeance ratings. ASTM E1745 "Standard Specification for Plastic Water Vapor Retarders Used in Contact with Soil or Granular Fill under Concrete Slabs" sets performance requirements for permeability, tensile strength and puncture resistance. ASTM E1745 was originally published in 1997 and high quality products only became widespread available in the 1990's. It took almost 45 years from the publication of "Housing Research Paper #28" to see membranes that met the recommendations put forth in 1954. To ensure the use of high quality membranes, Architects and specifiers must require ASTM E1745 compliance for vapor retarder products in project manuals and on plans.

This 1954 study contains valuable data that appears relevant to modern floor covering systems. The study was comprised of six (6) models that allowed water to be added as it evaporated through the concrete floor replicas. One model was comprised of 4-inch thick concrete, placed over 45-pound roll roofing membrane, over a 4-inch capillary break over the model's soil. While moisture loss was measured in cubic centimeters per day, an extrapolation to modern measures indicate the sample was passing the equivalent of 2.67 pounds of moisture per 1,000 square feet per 24 hours. In another model the concrete was set directly over soil with no vapor retarder or capillary break. This model passed the equivalent of 6.14 pounds of moisture per 1,000 square feet per 24 hours. A third model was created with 4-inches of concrete placed directly over a 4-inch capillary break without a vapor retarder. This model passed the equivalent of 19.72 pounds of moisture per 1,000 square feet per 24 hours. It has been this author's field experience that the greatest volume of vapor emission has been observed when concrete is poured over a capillary break without the benefit of an effective vapor retarder, mirroring the results noted in this 1954 study! There have been slab systems constructed in which crusher run rock was utilized for a capillary break and covered with 6-mil polyethylene sheeting beneath concrete slabs. Construction traffic had punched thousands if not millions of small holes in the plastic sheet before the concrete was ever placed. In one section of the United States it had been common to place clear plastic sheeting on prepared soil and dump rock over the plastic sheeting, the impact should be obvious.

This 1954 study proved the value of a sub-slab vapor retarder and indicated that concrete floor slabs could be created that would pass less than 3 pounds of moisture per 1,000 square feet per day. In the study's conclusions we find the following recommendation for slab-on-ground construction –

> ***"provide a membrane consisting of one layer of 55-pound roll roofing or one of the equally effective and durable new membrane materials, lapped 6 inches, turned up and extending to the top of the slab around all edges, with all laps carefully sealed with hot or solvent-type water proofing asphalt."***

Experience has shown us that paper felt and saturated felt products are not suited for long term exposure in the earth, none the less effective vapor retarders can inhibit or prohibit moisture migration into concrete floor slabs.

<u>1958</u>

In 1958 a study committee of the National Academy of Sciences, Building Research Advisory Board generated a report to the Federal Housing Administration entitled "Effectiveness of Concrete Admixtures in Controlling Transmission of Moisture Through Slabs-On-Ground". Without addressing admixtures tested at that time there are noteworthy statements in this document that relate directly to modern floor covering concerns. The following excerpts are as accurate today as they were in 1958.

1. ***"There are no nationally recognized standards concerning tolerable moisture transmission through concrete slab-on-ground construction under various conditions of use."***
2. ***"The Committee believes that regardless of the depth of the ground water table, or the amount or frequency of precipitation, one of the two following conditions are likely to exist beneath slabs-on-ground for sufficiently protracted periods to require protection against moisture migration -***
   A) One hundred percent relative humidity (100% RH) directly beneath the slab even under favorable soil and drainage conditions.
   B) Saturation or near saturation of cohesive soils beneath the slab."
3. ***"In a composite structure consisting of membrane, concrete, adhesive, and floor covering, or any combination of these materials, the water vapor pressure at any internal point will***

depend upon the vapor transmission qualities of each component of the system, as well as on the ambient conditions on both sides of the assembly."

4. ***"One of the tangible objectives of moisture protection of slabs-on-ground is the finish flooring. It should not be inferred, however, that all flooring materials require the same degree of protection from moisture. Research and development by the flooring industry has provided experimental data which have been used to estimate the degree of protection required. Certain flooring materials have demonstrated considerable resistance to damage from moisture, whereas other very desirable floorings need careful protection from excessive moisture."***
5. ***"One of the factors controlling the rate of moisture transmission through a concrete slab is the atmospheric condition on the dryer side."***
6. ***"Finish flooring materials tend to block the escape of moisture from the top side of the slab, and retard the escape of moisture into the space above. By so doing, however, an accumulation of moisture may take place directly under the flooring, and eventually harm the flooring material and its adhesive."***

Focusing on excerpt "***6.***" immediately above, it should be clear the permeability of a given floor covering material or system will impact the accumulation of moisture beneath the floor covering. In example - broadloom carpet manufactured on a woven polypropylene backing and installed stretched over a pad will constitute a highly permeable system. There should be no expectation that moisture would accumulate beneath this carpet system (unless plastic chairpads, solid based cabinets or other non-permeable objects are placed on the carpet). Conversely, carpet tiles created on pvc backing systems are highly impermeable and will trap escaping moisture if it is available. In a new construction environment, where concrete is placed on an effective vapor retarder or metal deck, moisture that may threaten floor coverings is limited to excess mix water not consumed hydrating cement. However, in remodel or reuse of slabs-on-ground, not isolated from earth by an effective sub-slab vapor retarder, the moisture that may threaten floor coverings is available from the earth itself. The above listed excerpt "***2.***" must be recognized for all slabs not underlain with an effective vapor retarder and project planning must assume 100% relative humidity will be achieved in the soils beneath the concrete, within the concrete and ultimately at the concrete/floor covering interface! In the author's opinion, this explains the meaning of excerpt ***"1."*** there were, and are no nationally recognized standards for tolerable moisture emission, or in-situ relative humidity under various conditions of construction and use. Numerous attributes of concrete itself affect the meaning of test data but without an effective sub-slab vapor retarder, test data must be recognized as non-predictive.

1965

In 1965 the Portland Cement Association published a study entitled Moisture Migration- Concrete Slab-On-Ground Construction authored by H.W. Brewer. This study is often quoted and contains a great deal of test data related to water-cement ratio of concrete and its effect on concrete drying and moisture migration. In relation to moisture testing of concrete and conditions that may affect the value of data collected, one of Brewer's conclusions is of greatest note:

> "***Application of an impervious barrier (such as floor tile) on a partially dried concrete surface reduced evaporation but increased the moisture content of the concrete when moisture was available below the slab."***

The Brewer conclusion continues with the statement ***"This occurred even when a vapor barrier was present".*** However, this conclusion that needs to be tempered by the fact that Brewer used 4-

mil thick polyethylene sheeting and 55 pound roofing felt as vapor retarders in his models. These materials are clearly not akin to sheet metal, nor would they meet current performance standards required by ASTM E1745.

The installation or application of floor coverings, as described by Brewer, is critically important to grasp and understand, as it dramatically effects the interpretation of moisture tests set on or in concrete slabs-on-ground in remodel projects. In example - If a concrete floor slab-on-ground is hosting a highly permeable or relatively permeable floor covering system and reuse will require the installation of a highly impermeable floor covering system, what test data should be considered? It is the author's opinion that concrete dryness or moisture tests are completely ineffective and the data all but meaningless, unless there is a high quality sub-slab moisture vapor retarder directly beneath the floor slab. Unfortunately, this is not the condition of most slabs placed prior to 1996 and of too many slabs placed since. Brewer's finding implies that moisture tends to enter concrete from below more slowly than it evaporates from its surface. Thus, the application of a vapor retarding membrane (*aka* new floor covering) will facilitate an increase of moisture within the concrete if there is not an effective sub-slab vapor retarder below the concrete.

The American Concrete Institute (ACI) publication ACI 302.2R-06 "Guide for Concrete Slabs that Receive Moisture-Sensitive Flooring Materials" contains the most succinct statement related to testing concrete slabs-on-ground placed without the benefit of an effective sub-slab vapor retarder –

"Warning – A moisture test should not be used to predict future concrete drying behavior, to provide evidence that moisture criteria are satisfied, or to establish expected floor covering performance if the concrete slab has not been placed directly on a vapor retarder/barrier".

In the author's opinion, this warning should be applied to all concrete slabs-on-ground placed prior to 1996 and to all such slabs placed since, if documented evidence of a properly placed vapor retarder meeting ASTM E1745 performance standards cannot be produced. Clearly, coring through the slab and performing a physical examination beneath the concrete is an acceptable means of creating documentation. ASTM E1745 has a companion standard that is no less vital to the effectiveness of moisture control. ASTM E1643 "Standard Practice for Selection, Design, Installation, and Inspection of Water Vapor Retarders Used in Contact with Earth or Granular Fill Under Concrete Slabs" should be enforced on plans and specifications to ensure a vapor retarder is properly installed beneath concrete slabs-on-ground.

In the United States concrete moisture testing has historically taken a number of forms including the use of electronic meters and calcium chloride salts. It is not the author's intent to review this equipment or methods of testing. However, as a token to history, the author was a distributor salesman representing Kentile™ in the 1970's. At that time, and likely earlier, Kentile's recommended method for testing concrete dryness was to create a small ring of putty on a concrete slab surface, place a teaspoon of calcium chloride salt inside the ring and cover the putty with a watch glass. If after 24 hours the salt had not dissolved, the concrete was dry enough to support floor covering installation. This "test" would have no relevance to modern floor coverings or adhesives. Calcium chloride salt's use slowly progressed from qualitative to quantitative and has been codified since 1998 under ASTM F1869 "Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride"

<u>1980</u>
European's did not follow the same path as the United States in regard to concrete and moisture. The Lund Institute for Technology in Lund, Sweden reports researching moisture in materials and buildings since 1964. The earliest Lund University paper in this author's library was published in 1980. The study was authored by Lars-Olof Nilsson and entitled "Hygroscopic moisture in concrete – drying, measurements & related material properties". This study encompasses 179 pages of text, charts and data, which I will not attempt to fully examine in this document. The study was performed by Lund's division of Building Materials and the study's preface states:

> ***"The present work was initiated in 1973 by Dr. G. Fagerlund, at that time head of the division, as a research project with the title "Applied moisture problems in connection with material combinations and surface layers" with financial support from the Swedish Council for Building research. The project was soon concentrated on solving the moisture problems arising when tight coverings are applied on concrete floors. This was done by developing calculation methods for drying of materials with an excess of moisture, mainly concrete. Existing methods suffered from a lack of required material properties and this is where the main effort has been put in this work. The expected results were considered as having a great significance for use in practice since a great number of damages occur every year due to unsatisfactory drying-out of excess moisture."***

The study focused on numerous attributes of concrete and methodologies of determining dryness. Besides the use of relative humidity measurements, the study showed results of testing moisture content as a percent of dry weight and testing with calcium carbide. The study's summary states:

> ***"Determining the <u>moisture content of concrete*</u> requires rather large samples in order to be accurate. The accuracy depends mainly on the size of the sample and the size of the stones. A small sample of concrete with large stones is usually not representative for the concrete composition and a measured moisture content may be very erroneous.***
>
> ***There are several advantages in measuring the relative humidity in concrete instead of the moisture content. The RH expresses the state of the moisture in a far better way, and it is certainly the state (of moisture) and not the content, that is of interest in most cases. In addition the relative humidity can be measured on small samples<u>, not necessarily representative for the concrete**,</u> with an accuracy shown to be much better than when measuring the moisture content."***

<u>"moisture content of concrete*"</u> in this sentence refers to moisture content as a percentage of dry weight. Making such a measurement requires taking a fairly large piece of concrete mechanically from a slab and drying in an oven until no weight loss is registered. Comparing "dry" weight to initial weight allows calculating moisture content. The study notes the importance of recognizing aggregate sizing when analyzing moisture content by dry weight.

<u>"not necessarily representative for the concrete"**</u> The study correctly suggests that a single data point should never be considered representative of a concrete slab's condition.

In this 1980 study's discussion of the need to establish a test method or methods we note the following:

> ***"Most materials are affected by moisture in one way or another. The moisture in concrete affects the concrete itself as well as materials in contact with it. The actual moisture content or condition should then be compared to a limiting value where the effect of moisture becomes too crucial. This limiting value is called the Critical Moisture Condition. Damage to materials sensitive to moisture is in most cases a result of moisture induced dimensional changes and/or a deterioration of the material. The critical moisture conditions should generally be described in terms of the state of moisture instead of the amount, as different materials or substances are usually involved and affect one another by exchanging moisture. At equal temperature such an exchange can be described by the relative humidity of the material, i.e. the pore humidity."***

This study gives credence to the use of relative humidity measurements in concrete as a means of determining suitability for the installation of floor coverings. However, one caution noted in the report is the cause of erroneous data collected today!

> ***"Even a small temperature difference between the concrete and the (RH) sensor gives an error."***

Sensors inside of in-situ probes must be at temperature equilibrium with the concrete itself, this is true regardless of the probe's manufacturer.

1997

A specific Moisture Research Group at Lund was formed in 1981 and the name most commonly referred to for his extensive work with concrete is Goran Hedenblad. Mr. Hedenblad's 1997 publication of "Drying of Construction Water in Concrete" is, to my understanding, the source of study data that set the standard for depth of measurement when employing in-situ relative humidity probes in newly placed concrete. Mr. Hedenblad's study found that testing concrete in-situ RH at 40% of slab thickness would approximate the RH to be anticipated through the thickness of concrete after a floor covering had been installed. This would be true if the concrete was slab-on-ground and had been fitted with an effective sub-slab vapor retarder directly beneath it, or if it was suspended concrete placed on a metal deck. In either instance the concrete would dry from its top surface only. A second test depth value was established for suspended structural concrete drying from both its top and bottom surfaces. Test depth was indicated at 20% of total concrete thickness for concrete drying from both top and bottom surfaces. All value of testing assumes no intrusive moisture source to rewet the concrete *i.e.* an effective vapor retarder must be present beneath slabs-on-ground.

Current Concerns

A reasonable question remains – how long does it take for moisture to equilibrate through the thickness of concrete after floor coverings or coatings are applied? During a recent investigation concrete in-situ RH was measured at depths of 20%, 40% and 60% to profile any gradient that may exist. The concrete was approximately 6 months old when flooring was installed and the floor coverings had been in place for approximately 8 months at the time of testing. Floor covering consisted of glued down VCT and floating vinyl planking. Regardless of floor covering type, testing indicated a 10% to 13% RH gradient still existed through the range of elevations.

Testing protocol in the United States follows standards written by one or more standards writing organizations. The American Society for Testing and Materials aka ASTM is one such organization. ASTM F2170 "Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using in situ Probes" was initially published in 2002 by committee F.06 on Resilient Flooring. The standard has undergone revisions in an effort to improve the document and has a current designation of ASTM F 2170b. Strictly following the requirements of this test standard will offer the user a data set of in-situ RH measurements. It is the use and/or interpretation of the data that caused the words "Friend or Foe" in this paper's title.

It is the author's opinion that data collected from the performance of concrete in-situ RH tests is often incorrectly collected and/or misused. All of the studies referenced above relate to concrete dryness and moisture emission. Study samples used to evaluate concrete drying were isolated from external moisture sources. Studies that evaluated the potential influence of external moisture sources acknowledged the need to place concrete over a highly effective sub-slab moisture vapor retarder. Concrete dryness testing data by any means is most meaningful for new suspended concrete or slab-on-ground when directly underlain with a vapor retarder meeting ASTM E1745 performance standards. The use of any test method in or on concrete not protected from intrusive moisture sources must be recognized as non-predictive and of little practical use. All concrete dryness test data should be accompanied by proof that an effective moisture vapor retarder is in place directly beneath the slab. Otherwise, test data reporting should caution that all test results are subject to dramatic change without notice.

Manufacturers of floor covering systems and components do a disservice to customers and end-users when offering exceedingly high moisture limits on products or systems specified for installation in remodel and reuse projects. Given sufficient time and access to the ambient environment, concrete will dry and internal relative humidity will match or approach ambient RH. Testing older concrete and achieving results significantly higher than the ambient condition should be fair warning that any vapor retarder placed during initial construction is deteriorated or does not exist. Therefore, there should be expectation that sub-slab soil and concrete in-situ RH will achieve 100% at some time during the life use of the flooring. Installing a floor system that permits installation when concrete in-situ RH is 90% will likely result in distress or complete failure at some point in the future. Two examples from the author's files follow below:

1. A laboratory was constructed as part of a re-model/reuse in and office/warehouse facility. The floor slab was tested by a floor covering contractor and deemed to need a "high moisture" adhesive. The basis for the decision was in-situ RH tests placed in areas that had hosted broadloom carpet. The tests indicated in-situ RH averaging 85% in a slab that was 25 years old. Adhesive warranted effective to 90% was utilized to install homogeneous sheet vinyl flooring during the conversion. Within 120 days the floor system failed. Adhesive had become soup and sheet seams had split. One piece of anecdotal evidence collected during failure investigation was revealed lifting walk-off mats set on the warehouse floor at entries into the new lab. Condensate moisture was in abundance beneath all of them! There was evidence available that should have indicated the lack of any sub-slab moisture protection. This failure should not have occurred and the cost of remedy was substantial.
2. The author was commissioned to test a grocery store that was to be remodeled and expanded into its existing warehouse. The facility was approximately 45 years old and had been previously remodeled. The sales floor was VCT, which was to be replaced with solid vinyl planking (LVT). In-situ RH testing performed in areas hosting VCT revealed 80% to 89%

relative humidity. Tests set in the warehouse concrete, which had never hosted floor coverings offered in-situ RH readings below 70%. My report to the owner stated the data indicated the lack of an effective vapor retarder beneath this slab. I opined the need to install a topical remediation system if new, directly adhered, floor coverings were to be installed.

Of note in the second example, the warehouse floor appeared to test suitably dry. If that data were used as the basis for determining concrete suitability for floor covering installation, there is little question the failure described in first example would have been repeated. While examples above are limited to two, hundreds if not thousands of similar stories could be reported.

In too many instances in-situ probes are being placed and not allowed sufficient equilibration time to achieve meaningful data. This author has been given data sheets indicating test well and sleeve equilibration of 72 hours, but probe placement and reading after 5 minutes. Each probe manufacturer's guidelines should be followed, but having probes travel in a hot or cold automobile and set in test sleeves for 5-minutes should never be an accepted practice. As reported in 1980, even a small variance between sensor temperature and concrete temperature will cause error.

Summary

It is not the author's intent or desire to end concrete dryness testing, nor does this paper cover all aspects of concrete and the myriad of current floor slab designs. However, there needs to be greater emphasis at all levels of floor system design, specification, sales and installation regarding the need to evaluate any concrete moisture test data against the array of factors that affect the value of test data. This will only be achieved through education, a greater depth of systems understanding and a ferocious desire to prevent failures.

Any test properly performed and evaluated can be a Friend. Testing performed improperly, under conditions that are not fully evaluated with data misinterpreted will indeed become a Foe.

The value of improper testing and poorly prepared reporting is appreciated only by opposing legal counsel if a failure turns to litigation.

Bullet Points For In-situ Test Data Evaluation

1. All concrete dryness testing reflects a picture in time!
   a. New concrete should become drier and eventually achieve a stable moisture content, if suspended, placed on a metal deck or underlain directly with a high quality vapor retarding membrane.
   b. Regardless of age, concrete slabs-on-ground should never be considered moisture stable unless a sub-slab moisture vapor retarder is present. Soil moisture content at or approaching 100% will be reflected in the concrete after impermeable flooring is installed. Any decision to ignore this maxim should be in the hands of the person that will pay for a failure.
2. Concrete in-situ RH testing performed at 20% or 40% of concrete thickness, reflects moisture at that elevation only! (This Section For Suspended or S.O.G. with V.R. Only)
   a. There is no mathematical equation that permits us to anticipate the amount of time required to achieve equilibration of moisture in concrete after floor coverings or coatings are installed.
   b. Less than impermeable floor systems will permit additional and continuous drying at the near surface of the concrete. Equilibrium may only be achieved after a period of years, ultimately attaining equilibrium with the ambient environment.
   c. Unless floor covering is impermeable, the floor covering/concrete interface may never reflect moisture levels noted at the test depth.
3. Test data collection should be performed in strict accordance with ASTM F2170.
   a. If exceptions to the standard test method protocol are required, all exceptions must be fully documented for review by others.
   b. All parties are best served by fully documenting test procedures, ambient conditions during the test period and photographic evidence of measurements.
4. Sensors inside of probes must be at temperature equilibrium with the concrete to be tested!
   a. One study showed a 3% error factor for each 1°C (1.8°F) that temperature between the sensor and concrete were out of equilibration.
   b. ASTM F2170-16b states meter readings must not drift more than 1% RH over a 5-minute period. This is insufficient, drift is slow, and one should expect it to take between 1 and 2 hours after probe insertion to achieve stable readings.
5. Test probes available in the market have sensors that cannot be expected to deliver exact results!
   a. ASTM F2170 requires probes/sensors to display accuracy to +/- 3% when calibration is checked against a saturated salt solution with nominal RH value between 90% and 100% *i.e.* Potassium Sulfate generates RH of 97.6% at 68°F.
   b. One senor manufacturer warns that sensor signal (readings) may temporarily offset +3% if the sensor is subjected to high RH (over 80%) for greater than 60 hours.
   c. Flooring product and/or system offerings that permit installation when in-situ RH is no greater than 93% or 95% or 99%, have no means of verification if a claim arises.
6. No two concrete slabs are the same. Variance in thickness, concrete mix design *i.e.* water/cement ratio, aggregate sizing, aggregate consolidation, SCM content, curing method, finishing method and ambient conditions during drying, are all factors that affect the rate of drying and the predictive value of in-situ RH test data. **However, none of these factors is of any concern if slab-on-ground concrete is not directly underlain with a vapor retarder meeting ASTM E1745 performance standards and installed to ASTM E1643 placement requirements**.

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ASTM F1869 Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride

ASTM F2170 Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using in situ Probes

ASTM E1745 Standard Specification for Plastic Water Vapor Retarders Used in Contact with Soil or Granular Fill under Concrete Slabs

ASTM E1643 Standard Practice for Selection, Design, Installation, and Inspection of Water Vapor Retarders Used in Contact with Earth or Granular Fill Under Concrete Slabs
All ASTM standards available through - ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959

ACI 302.2R-06 Guide for Concrete Slabs that Receive Moisture-Sensitive Flooring Materials
American Concrete Institute, Committee 302
38800 Country Club Drive, Farmington Hills, MI 48331