Arnold Schwarzenegger
Governor

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CONCRETE SLAB CONSTRUCTION PRACTICES EXPERIMENT RESULTS REPORT

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Gas Technology Institute

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Concrete Slab Construction Practices Experiment Results

Task 3.3 Report

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(GTI Project No. 15485)

for

California Energy Commission

Contract No. 500-03-013

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February 2006

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Executive Summary

The American Concrete Institute's "Guide for Concrete Floor and Slab Construction" (ACI 302.1R-04) presents two options for the location of a below-slab vapor retarder. To compare the effect of location on the performance of a sub-slab vapor retarder, concrete slabs were constructed and monitored by GTI at its Des Plaines, Illinois, facility. Placing concrete in direct contact with the vapor retarder was compared to the common California contractor practice of sandwiching a layer of sand between the slab and the vapor retarder. The experiments compared concrete drying rates and length of time to reach and maintain desired relative humidity levels. Moisture loading test procedures for concrete slabs evaluated the impact of the vapor retarder location and fill material on curing and drying rates after the pour, and relative humidity and concrete moisture content throughout a heating season, after installing vinyl tiles, and when subjected to water loading from below grade subsequent to the pour. Test parameters included subslab fill material (sand or crushed stone), moisture loading, ambient conditions, and location of vapor retarder relative to the subslab fill material. Measured parameters included temperature and relative humidity of the slab at 1" below slab surface, moisture content at various depths below slab surface, and temperatures above and below the slab. Resistance moisture pins inserted into a ¼" square by 2" long wood block measured the moisture content of the wood embedded in the concrete.

Slabs were poured by hand on October 14, 2004, using nominal 2,500 PSI concrete. The automated data acquisition system was installed on October 22-25, 2004. Slabs were covered with insulated enclosures and ground insulation was added on November 24, 2004. Slabs remained covered for the remainder of the test period until August 26, 2005. Heating with electric resistance heaters commenced on December 4, 2004, to maintain approximately 20 to 22ºC air temperature above the slabs. Vinyl tiles were glued to slabs on April 5-6, 2005, to determine the impact of sealing the surface on moisture content and relative humidity. On May 18, 2005, water was poured into the sand or crushed stone under the slabs to simulate groundwater intrusion below the slab.

All eight slab sections had moisture content slopes reasonably consistent with expected drying rates after the slabs were enclosed and heated. Moisture content in all slab sections approached equilibrium 5 months after the pour in March 2005. Vapor retarder location and fill material affected moisture content profiles after slabs were covered, but not always in accordance with a priori expectations. Tile installation did not affect moisture content at 1" depth in most slab sections, with anomalous changes observed in slabs 2, 3, 4, and 5 immediately after tile installation. The 2 gallon water pour in each slab section resulted in significant changes in moisture content in all five 4" slabs (1, 2, 3, 4, and 7) not having the vapor retarder directly beneath the slab. Conversely, all three 4" slabs (5, 6, and 8) with vapor retarder in contact with the slab had much smaller increases, especially in the first month after the water pour. Also, slab 5 moisture content was significantly higher than slab 8 moisture content at 1" depth in the 4" slab and at 6" depth in the grade beam, but not at 1" depth in the grade beam.

Relative humidity at 1" depth in all 8 slab sections fell below 80 percent within 4 months after pour in both the 4" slab and 12" grade beam, with significant changes in relative humidity occurring 3 months after the pour, shortly after sensor installation. Relative humidity variations between the 4" slab and 12" grade beam suggest that no entire slab section was ready for floor covering until 4 months after the pour.

The data suggest that moisture content may be a reasonable predictor of changes in relative humidity, but does not appear to be a good predictor of exact relative humidity values in any individual slab section or moisture content level.

Data collected during this research project provided evidence of the beneficial long term impact of the direct contact option shown in ACI 302.1R-04 on slab moisture content and relative humidity. The data did not show a noticeable impact of fill material on moisture content or relative humidity. However, the

data also yielded some inconsistent and sometimes contradictory results, both for moisture content and relative humidity measurements. Consequently, all project results are considered informative, but not authoritative. Nonetheless, many of the project results were sufficiently compelling to warrant further research.

Additional laboratory and field installations are recommended using collocated moisture pins and temperature and relative humidity sensors to improve the understanding of any correlations among moisture content, relative humidity, and vapor emission rate. An initiative to develop consensus based test methods and criteria through an organization such as ASTM is recommended to determine and validate the predictive power of various measurement methods.

Task 3.3 – Concrete Slab Construction Practices Experiment Results

Background

The first technical task (Task 2) of the "Energy Efficient Mold-Resistant Building Assemblies and Construction Practices for California Homes" project was to perform a situation analysis of mold problems and state-of-the-art methods of addressing these problems in the residential new construction market in California. The overall goal of Task 2 was to identify the most challenging mold problems facing California builders and recommend potential solutions for detailed laboratory evaluation and possible use in demonstration homes to be built by the two participating builders. Based on discussions with Commission staff, the project team, Project Advisory Committee (PAC) members, and building industry experts, the highest value areas for this project to address with laboratory testing were water-resistive barrier (WRB) design options (especially around windows), concrete slab installation practices and materials (especially vapor retarder location and fill materials), and drying times for built up wall assemblies.

This focus was intended to provide defensible, repeatable results that advance the understanding of overall wall system performance. Components and subsystems have been tested for mold growth and impact of moisture by building scientists, universities, and manufacturers. The recommended focus builds on that testing to provide a better understanding of the behavior of the entire wall assembly as well as collect unique data on the performance of wall cavities and materials as a part of a complete assembly. This approach also allowed flexible and innovative configurations of materials and installation methods to be tested using a combination of available test protocols and new test methods developed specifically to meet project goals.

Specific laboratory tests and protocols developed in conjunction with project team members, builders, PAC members, Commission staff, and industry consultants were summarized in the Laboratory Evaluation Test Plan (Task 3.1). The test plan provided the initial framework for laboratory evaluations. Based on experience gained during the performance of laboratory tests, the project team updated test goals, protocols, facilities, and test matrix to maximize the value of each test.

Goal

The overall goal of Task 3 was to perform a systematic laboratory evaluation of conventional and innovative residential building materials, assemblies, and construction practices identified in Task 2. Task 3 laboratory evaluations were designed to provide experimental evidence of moisture loading, propensity for mold formation, and potential performance improvements associated with innovative building assemblies and construction practices.

The goal of Task 3.3 was to evaluate conventional and innovative construction practices (i.e., the way individual components and building assemblies are installed in the field) identified in Task 2.4 in accordance with the Laboratory Test Plan developed in Task 3.1. To meet this goal, the project team performed a series of experiments in a controlled environmental setting at GTI's laboratory facilities. Experiments focused on moisture loading and climatic cycling action on assembled systems representing targeted building construction practices. These tests provide empirical data using existing and newly developed test protocols that should permit replication by other testing organizations and provide a technical basis for demonstration home design recommendations in Tasks 3 and 4 and builder guidelines in Tasks 3 and 5.

Scope

Laboratory evaluations under Task 3.3 addressed the following construction practices:

1. Evaluate performance of drainage plane design alternatives around conventional vinyl windows in 3-coat stucco wall construction; and
2. Measure moisture content over time of concrete floor slabs and footings with targeted vapor retarder locations and fill materials in the drying period after the slab was poured and when the slab fill materials were subjected to subsequent water intrusion events.

This report focuses on concrete floor slab experiments. A separate report discusses the performance evaluation of WRB design alternatives around windows.

Approach

Concrete slab laboratory experiments focused on vapor retarder installation options described in ACI 302.1R-04 "Guide for Concrete Floor and Slab Construction". The ACI 302.1 direct contact method (Figure 1) was compared to common California contractor practice (Table 1) using slabs constructed and monitored by GTI at its Des Plaines, Illinois, facility. Moisture content experiments on concrete slabs used embedded wood moisture pins and temperature and relative humidity sensors to evaluate slab moisture conditions after the initial pour, after placing glued vinyl tiles on the slabs, and after injecting water into the fill material underneath the slab to simulate changes in water content of the soil. In addition, ambient conditions, soil temperatures, and air temperature above the slab were monitored.

The key differences between the direct contact option described in ACI 302.1 and current California construction practices are fill material and vapor retarder placement relative to the slab. The ACI 302.1 direct contact option calls for the vapor retarder to be installed directly underneath the slab with compactable drainable fill beneath the vapor retarder, rather than having a sand buffer between the vapor retarder and the slab, which is typical California construction practice. The goal of the ACI 302.1 direct contact option is to isolate the slab from water present or collected in the blotter layer that would enter the slab and increase the slab moisture level, which could cause flooring failures and possibly mold problems.

According to concrete industry participants, most floor coverings require relative humidity reading of 75 to 80% or less at a depth of 40% slab thickness to avoid moisture related problems. The experimental design was intended to determine the impact of vapor retarder location and fill material on concrete drying rates and length of time to reach and maintain desired relative humidity levels. The experiments also permitted an evaluation of differences between the slab and grade beam. For instance, after an impermeable covering is installed, moisture from deeper in the grade beam may cause a higher equilibrium relative humidity in the grade beam than in the slab.

To evaluate moisture content in concrete over time, relative humidity in slabs is often measured in accordance with ASTM F2170 "Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using in situ Probes." An alternative approach is to measure concrete moisture content indirectly by using wood embedded in the concrete. It was expected that moisture content of embedded wood would correlate well with concrete slab relative humidity (Figure 2), and would also provide a reasonable indication of the concrete water content profile. Figure 3 shows the impact of hydration, capillary drying, and diffusion drying on concrete water content over time. The experiments measured moisture content and relative humidity to evaluate the correlation between wood moisture content and relative humidity in the slabs.

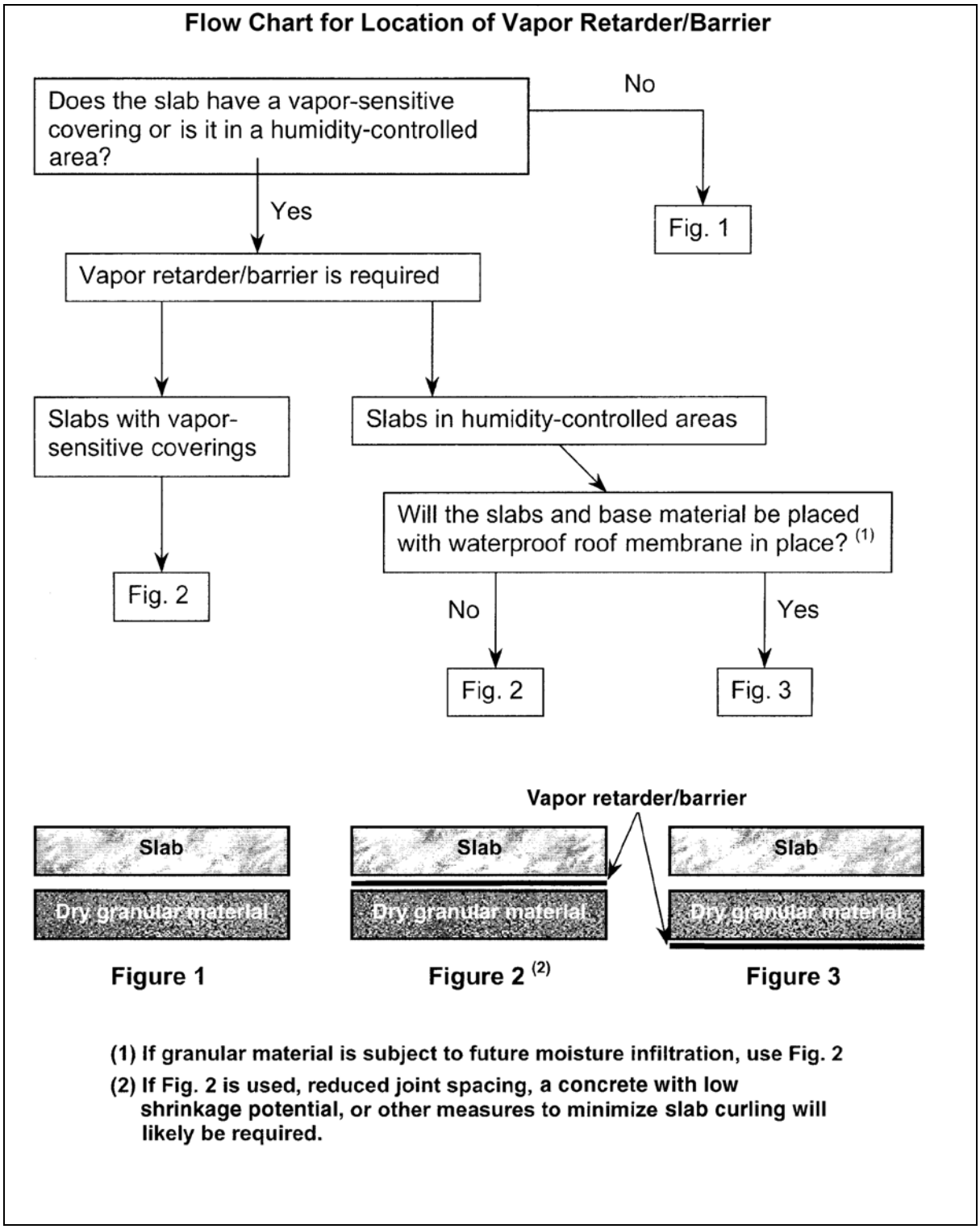


Figure 1 ACI 302.1R-04 Options for Vapor Retarder Location
(Source: ACI 302.1R-96 Addendum)

Table 1 Survey of California Concrete Installation Practices

Name	***Company***	***Procedure***	***Comments***
Dave Clark, Owner	Team C Construction	2” sand; 6 mil poly barrier; 2” sand; concrete	Numerous commercial slabs; couple large residential/mo.; typical placement per design spec on drawing.
Paul, Inside Sales	White Cap Concrete Products	Familiar with placement procedures of thousands of residential slabs in Southern California. No typical placement. CA Building Code (CBC) specifications vary depending upon location; type of soil; prior construction; radon, moisture, seismic concerns (“There’s a three-inch thick book on these procedures.”). Local Building Codes generally comply with CBC. Compaction, amount of sand/gravel, type/placement of vapor barrier, and placement of concrete are dictated by these issues.	
Kevin Thompson, Outside Sales	White Cap Concrete Products	2” sand; 10 mil poly barrier; 2” sand; 4” concrete	He is familiar with concrete placement throughout the state; says this is typical; the top layer of sand is primarily to prevent any reinforcing mesh or steel from puncturing the vapor barrier.
Dave Konstantin, Owner	KCO Construction	2” masonry sand; 4 mil poly barrier; concrete	50 residential slabs/year; not sure about code, follows design spec on drawing.
Victor, Field Supt.	Verdugo Concrete	2” sand; 10 mil poly barrier; 2” sand; 5” concrete	Over 1000 slabs/year; this is typical pour; sometimes spec calls for 20 mil barrier.
Steve, Owner	Mueller Lewis Concrete	2” #30 sand; 10 mil poly barrier; 2” #30 sand; 4 – 5” concrete	1200 – 1500 slabs/year; typical pour; spec used to be 6 mil retarder, increasingly it’s 10 mil poly.

Source: Magus Consulting Services Contractor Survey, March 2004

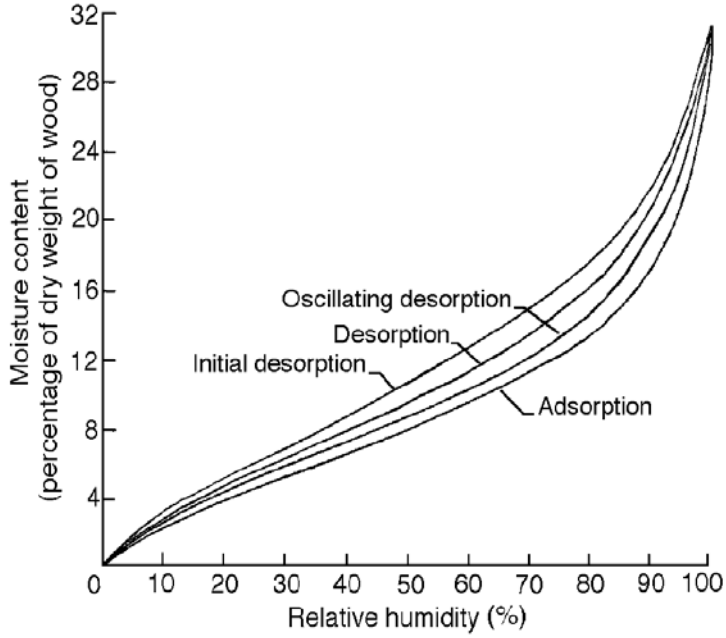


Figure 2 Wood Moisture Content/Relative Humidity Curve
(Source: Forest Products Laboratory 1999 Wood Handbook—Wood as an Engineering Material, Figure 3-2)

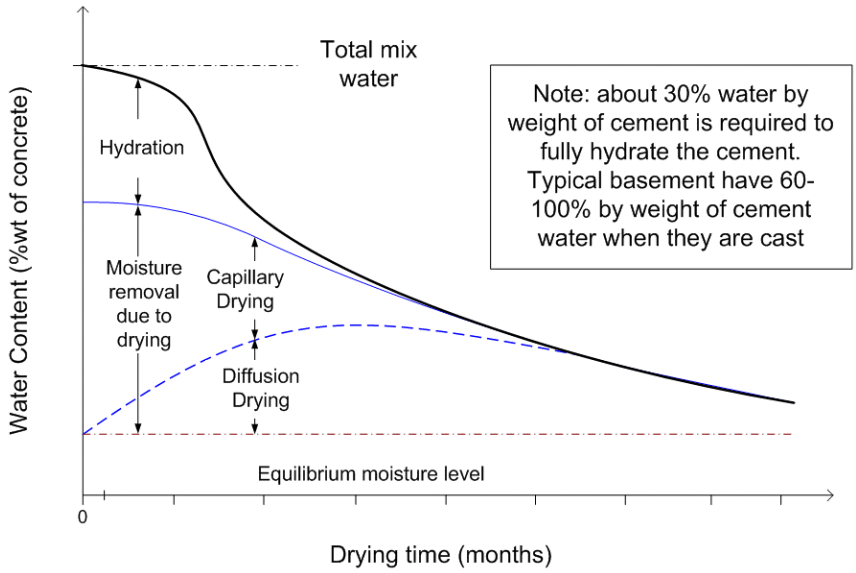


Figure 3 Concrete Drying Process
(Courtesy John Straube, University of Waterloo)

Note: Concrete Water Content for Slabs was 60% by Weight

Protocols

Experimental protocols were designed to allow exploration of a number of hypotheses regarding concrete slab drying and slab conditions, including:

- Concrete drying time to approach equilibrium conditions takes several months, and possibly years, depending on slab thickness, concrete mix, initial water content, surface coatings, subslab treatments, and soil conditions.
- Relative humidity differential is a key driving force for vapor movement through concrete slabs.
- Moisture vapor emission rate at the slab surface is a key parameter of interest for flooring and mold problems. Relative humidity at 40% slab depth and concrete moisture content measured using embedded wood resistance pins may be reasonable indicators of dynamic vapor emissions.
- Vapor emission rate at the slab surface is a complex function of concrete mix and additives, presence of vapor retarders above and below the slab, concrete moisture content, slab temperature, air temperature above the slab, relative humidity above the slab, soil moisture content, and soil temperature.
- Relative humidity and slab moisture content measurements are not meaningful until the slab is covered and heated, due to precipitation and variable temperature impacts.
- Relative humidity sensors sheilded with Tyvek® and embedded in concrete during the hydration period would fail quickly due to high alkalinity and saturated moisture conditions.
- Moisture content sensors using wood moisture pins should not be affected by alkalinity or high moisture levels during the hydration period.
- Wood pin moisture content should correlate with relative humidity and both should respond in a predictable way to experimental and ambient changes in air, slab, subslab, and soil conditions.
- Relative humidity and moisture content profiles after vinyl tile installation should depend on vapor retarder location and fill materials.
- Addition of 2 gallons of water should increase relative humidity by as much as 30% (or to saturation), and wood moisture content by as much as 8% depending on vapor retarder location and fill materials.

Moisture loading test procedures for concrete slabs evaluated the impact of the vapor retarder location and fill material on curing and drying rates after the pour, and relative humidity and concrete moisture content throughout a heating season, after installing vinyl tiles, and when subjected to water loading from below grade subsequent to the pour. Test parameters included subslab fill material (sand or crushed stone), moisture loading, ambient conditions, and location of vapor retarder relative to the subslab fill material. Measured parameters included temperature and relative humidity of the slab at 1” below slab surface, moisture content at various depths below slab surface, and temperatures above and below the slab. Resistance moisture pins inserted into a ¼” square by 2” long wood block (designed by Balanced Solutions, Inc. for this project) measured the moisture content of the wood embedded in the concrete.

Figures 4 through 21 show schematics and installation details of the eight 4” thick concrete slab sections and 12” deep by 12” wide grade beams, including embedded moisture pins, relative humidity sensors, and water injection tubes. Each slab section was separated from other slab sections using full height 1” thick polystyrene insulation boards. To partially decouple the slabs from ground conditions during the Chicago winter, 1.5” thick by 4’-0” wide polystyrene insulation was placed on the ground adjacent to the slabs.

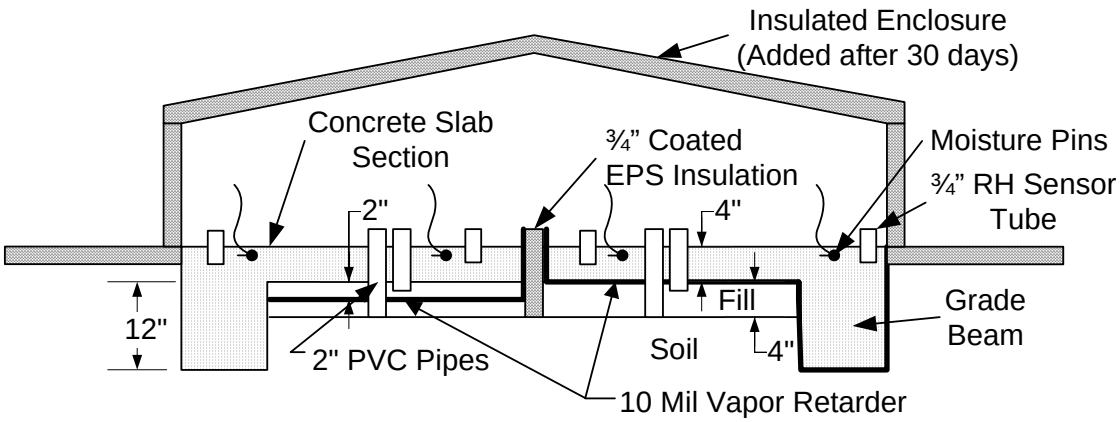
Slabs were poured by hand on October 14, 2004, using nominal 2,500 PSI concrete (mix design No. 9253) from Meyer Materials. Compressive strength in 3 coupons measured 28 days after pour (per ASTM C 39) averaged 2,910 psi. No visible cracks were observed in any of the slab sections at any time throughout the test period. Table 2 shows the concrete mix design.

Table 2 2,500 PSI Concrete Mix Design

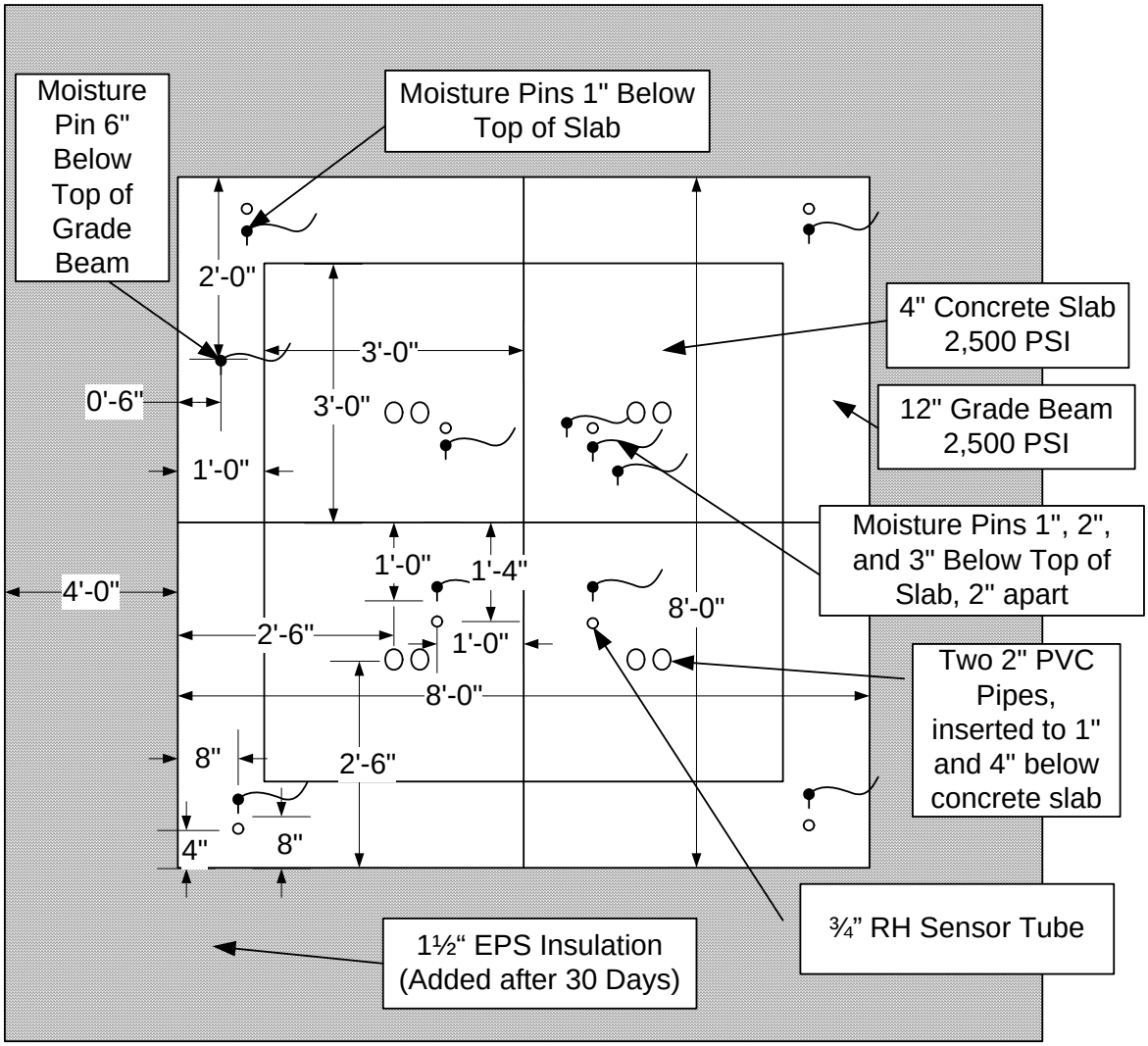
No-Air	Mix #9253	ASTM Specification
Cement	423 lbs.	C-150
Natural Sand	1,390 lbs.	C-33
57 Stone	1,900 lbs.	C-33
Admixture	As Required oz.	C-260 (A.E.A.)
Potable Water	30.5 gals.	
W/C Ratio	0.60	
Slump	4”±1”	
Air Content	6%±1%	

Temperature and relative humidity sensors in the slabs were thermistors and thin film capacitance sensors encased in Tyvek®, inserted into ¾” ID polyethylene tubes with Tyvek® barrier, embedded 1” below the slab surface. During the hydration period, a trial sensor was installed. The relative humidity sensor failed within a week in the alkaline environment. Installation of remaining sensors was delayed until January 2005 to avoid further sensor problems. In the meantime, a shielded RH sensor was installed in Slab A2 on December 12, 2004, and manually read periodically until the first week of January 2005. The wood moisture pins were not susceptible to degradation or sensor failure during the hydration period.

The automated data acquisition system for these tests was a Campbell Scientific CR10X datalogger, installed on October 22-25, 2004. Initially the concrete slabs were exposed to ambient conditions and not under cover. Slabs were covered with insulated enclosures and ground insulation was added on November 24, 2004. Slabs remained covered for the remainder of the test period until August 26, 2005. Heating with electric resistance heaters commenced on December 4, 2004, to maintain approximately 20 to 22ºC air temperature above the slabs. Vinyl tiles were glued to slabs on April 5-6, 2005, to determine the impact of sealing the surface on moisture content and relative humidity. The heating setpoint was also lowered to 18ºC in anticipation of warmer weather. On May 18, 2005, water was poured into the sand or crushed stone under the slabs to simulate groundwater intrusion below the slab. A 2” PVC pipe inserted at the center of the slab was used to pour water 1” under the bottom side of the slabs. The amount of water injection was 2 gallons per slab section.



Elevation



Plan

Figure 4 Concrete Slab Layout

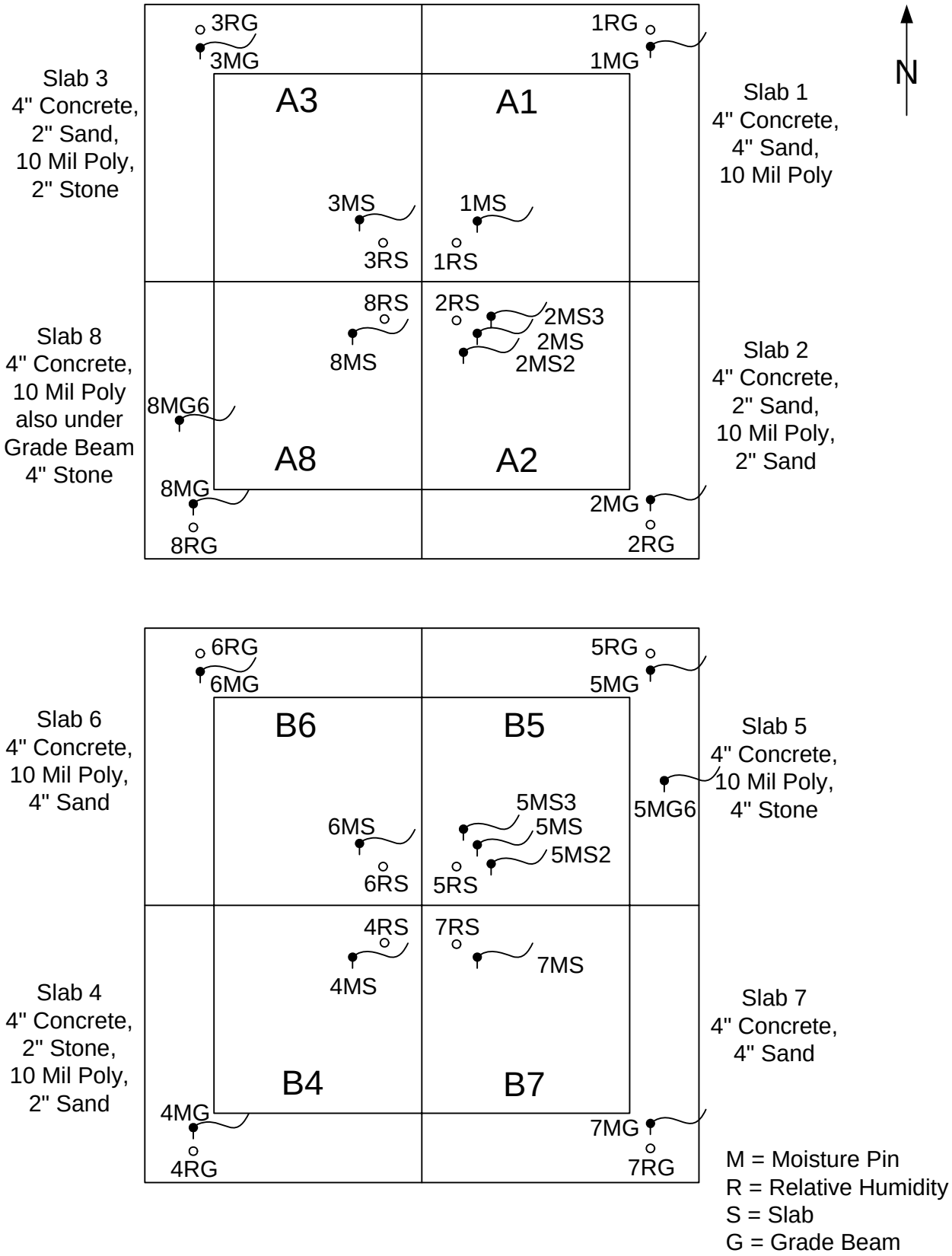
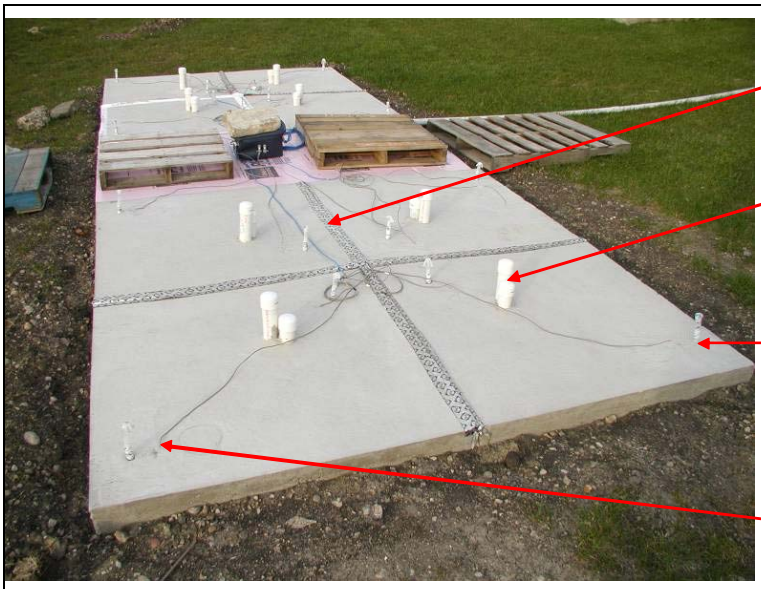
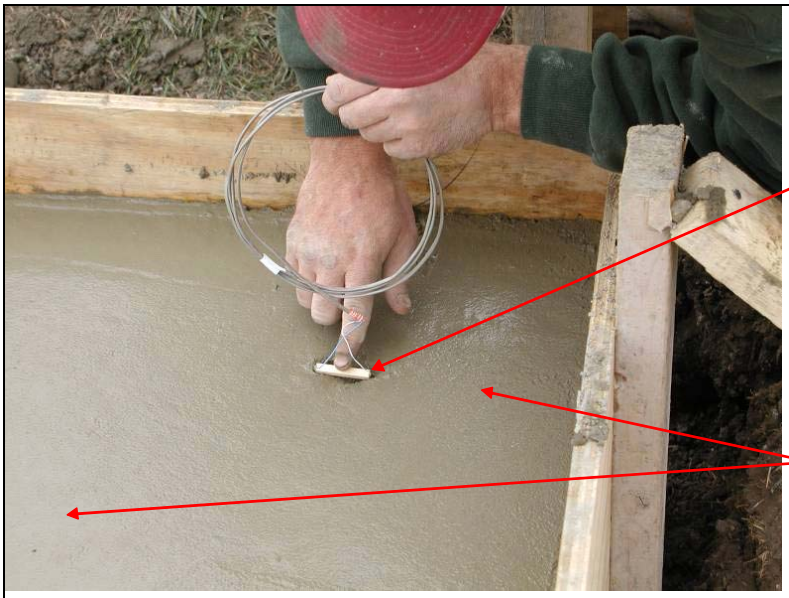


Figure 5 Concrete Slab Parameters



Two 8'x8' Slabs with Eight 4'x4' Sections to Test Impact of Vapor Retarder and Fill Locations on Moisture Content

Figure 6 Concrete Slabs A and B (Looking South)



Wood Resistance Moisture Pins Used to Measure Slab Moisture Content and Compare to Relative Humidity Measurements

Figure 7 Moisture Pin Embedded in Concrete Slab

Figure 8 Concrete Slab Framing with 1” Thick Insulated Dividers

Figure 9 Fill Material and Vapor Retarder Installation, Slab A

Figure 10 Fill Material Installation, Slab B

Figure 11 Vapor Retarder Installation, Slab B

Figure 12 Grade Beam Pour, Slab B, Showing Removal of Temporary Restraining Wall

Figure 13 Grade Beam Pour, Slab A8, with Continuous Vapor Retarder Under Grade Beam

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Figure 16 Relative Humidity Sensor Enclosure with Tyvek® Barrier

Figure 17 Finish Troweling and RH Sensor Enclosure Placement, Slab A

Figure 18 Insulated Concrete Slab Enclosures and Horizontal Foundation Insulation

Figure 19 Tile Adhesive Installation, Slab A

Figure 20 Vinyl Tile Installation, Slab B

Figure 21 Two Gallon Water Pour, Slab B4

Results

Moisture Content Prior to Tile Installation (November 24, 2004 - April 6, 2005)

All eight slab sections had moisture content slopes reasonably consistent with expected 6 month drying rates after the slabs were enclosed (Figures 22 through 31). In the month prior to enclosure, outdoor ambient temperature fluctuations (Figure 32) and especially precipitation (Figure 33) may have influenced concrete moisture content. Wood moisture content the day the slabs were covered varied from 23 percent to 29 percent. A few anomalies in moisture content occurred during the drying period, such as Slab 7 in the 12" grade beam, but overall, the drying curves were stable and relatively smooth.

Moisture content in all slab sections approached equilibrium 5 months after the pour in March 2005. Wood moisture content the day the tiles were installed varied from 12 percent to 21 percent. The insulated enclosure and horizontal ground insulation were effective at limiting the influence of ambient conditions and soil temperatures (Figure 34) on enclosure temperature (Figure 35) and slab moisture content over time as well as among slab sections and across slabs.

Enclosure temperatures in the 2 slabs were as much as 5ºC different before February 11, 2005, when slab RH sensor seals were repaired and heater setpoint in Slab B was increased from 18ºC to 22ºC. After that time, the temperatures were within 1 to 2ºC. These differences account for at least some of the variation in relative humidity observed between slabs A and B and within Slab B sections before and after February 11. The temperature differences did not appear to influence wood moisture content profiles.

Moisture content in the 12" grade beam slab sections at 1" depth was similar to the 4" slab prior to tile installation, except for Slab 5 (Poly, 4" stone). In Slab 5, the moisture content in the 4" slab was significantly higher than in the 12" slab.

Vapor retarder location and fill material affected moisture content profiles after slabs were covered, but not always in accordance with a priori expectations. For instance, slab 2 (2" sand, poly, 2" sand) and slab 5 had different moisture content profiles at 1", 2", and 3" depths than expected (Figures 25 and 29). Also, slabs 5 and 8 (poly under the grade beam as well as the slab) had significantly different moisture content levels at 1" depth in the 4" slab, but not in the 12" grade beam (Figures 27 and 29).

Slab 6 (Poly, 4" Sand) had significantly lower moisture content than the other 7 slab sections throughout the test period in the 4" slab, but not the 12" grade beam. Its drying rate was comparable to other slab sections prior to tile installation.

Slabs 5 and 6 had significantly different moisture content in the 4" slab, but similar moisture content in the 12" grade beam.

Slab 8 showed similar moisture content profiles at both 1" and 6" deep in the grade beam as slab 5 (no poly under grade beam) throughout the period. However, slab 8 had more rapid drying at 1" deep in the 4" slab.

Moisture Content after Tile Installation (April 7 2005 – May 18, 2005)

Tile installation did not affect moisture content in most slab sections. However, slab 3 (2" sand, poly, 2" stone) moisture content increased by 4 percent in the 4" slab (but not the 12" grade beam) during the month after tile installation. Slab 4 (2" stone, poly, 2" sand) moisture content in the 12" grade beam had a rapid 2 percent increase immediately after tile installation, but remained stable thereafter, while the

moisture content increased by 4 percent in the 4" slab during the month after tile installation (Figure 28). Slab 5 moisture content in the 4" grade beam had a rapid 2 percent decrease immediately after tile installation, but remained stable thereafter (Figure 29). Slab 2 moisture content at 2" and 3" depths in the 4" slab dropped slightly, then increased significantly (5 percent change) during the month after tile installation. Moisture content at 1" depth was significantly lower and did not change during the same time period.

Moisture Content after Water Pour (May 18, 2005 – August 26, 2005)

The 2 gallon water pour in each slab section resulted in significant changes in moisture content in all five 4" slabs (1, 2, 3, 4, and 7) not having the vapor retarder adjacent to the slab. Conversely, all three 4" slabs (5, 6, and 8) with vapor retarder adjacent to the slab had much smaller increases, especially in the first month after the water pour. Also, slab 5 moisture content was higher than slab 8 moisture content at 1" depth in the 4" slab and at 6" depth in the grade beam, but not at 1" depth in the grade beam.

Relative Humidity Profiles

Figures 36 through 39 show the relative humidity and temperature profiles for all 8 slab sections at 1" depth in the 4" slabs and at 1" depth in the 12" grade beams. Figures 40 through 55 provide temperature and relative humidity profiles for individual slab sections. Some or all of the taped relative humidity seals leaked to an unknown extent for short period of time prior to February 11, 2005, at which time they were repaired and remained intact for the remainder of the test period through August 26, 2005. From the shape of the relative and absolute humidity curves, it appears that noticeable leaks started around February 8, 2005. To be conservative, relative humidity data between February 1 and February 11 is considered invalid for analytical purposes.

Relative humidity at 1" depth in all 8 slab sections fell below 80 percent within 4 months after pour in both the 4" slab and 12" grade beam, with significant changes in relative humidity occurring 3 months after the pour, shortly after sensor installation. Relative humidity variations between the 4" slab and 12" grade beam suggest that no entire slab section was ready for floor covering until 4 months after the pour.

Tile installation and water pour both resulted in relative humidity conditions well above 80 percent, with some slab sections reaching 100 percent relative humidity shortly after the water pour. No slab section remained below 80 percent RH by August 26, 2005.

After slabs were covered, ambient conditions had little impact on 4" slab temperatures, but may have had some impact on 12" grade beam temperatures. However, enclosure temperature variations between slabs A and B had a much more significant impact on slab and grade beam temperatures. Relative humidity was influenced by enclosure air temperature differences between the slabs of as much as 5ºC.

Absolute humidity should not be influenced by rapid changes in concrete temperature (e.g., on April 6-7, 2005) and may provide another useful indicator of moisture conditions in the slabs. Figures 56 and 57 show absolute relative humidity profiles for slabs A and B. The 4" slab data showed discontinuities with absolute humidity differences as high as 20 percent when the tiles were installed. The 12" grade beam data showed much better continuity. Data prior to the RH seal failure repair also showed significant discontinuities (as much as 40 percent), but at least some of the difference can be attributed to the leak.

Relative Humidity vs. Wood Resistance Pin Moisture Content

Figures 58 and 59 show polynomial curve fits of hourly relative humidity and moisture content data compared to the predicted relationship, from April 8, 2005 through August 26, 2005. While the general

shapes of the curves align reasonably with the predicted relationship, the variability is significant, especially in slab B. Moisture content may be a reasonable predictor of changes in relative humidity, but does not appear to be a good predictor of exact relative humidity values in any individual slab section or moisture content level.

Conclusions and Research Recommendations

Data collected during this research project provided evidence of the beneficial long term impact of the direct contact option shown in ACI 302.1R-04 on slab moisture content and relative humidity. The data did not show a noticeable impact of fill material on moisture content or relative humidity. However, the data also yielded some inconsistent and sometimes contradictory results, both for moisture content and relative humidity measurements. In addition, all of the test protocols used in this project were tailored to meet project goals and were not based on consensus methods such as ASTM standards. Consequently, all project results are considered informative, but not authoritative. Nonetheless, many of the project results were sufficiently compelling to warrant further research.

Additional laboratory and field installations are recommended using collocated moisture pins and temperature and relative humidity sensors in to improve the understanding of any correlations among moisture content, relative humidity, and vapor emission rate.

It would also be helpful to develop data and rationales for target maximum moisture content and long term relative humidity levels. For instance, in this project, slab sections had relative humidity levels ranging from 65 percent to 90 percent after tile installation, and ranging from 80 percent to 100 percent by the end of the test period 3 months after the water pour. Coincident wood moisture content levels ranged from 12 percent to 23 percent after tile installation, and ranged from 14 percent to 28 percent by the end of the test period 3 months after the water pour. Relative humidity values suggest that all slabs may have high vapor emission rates long after the slab is poured, but moisture content readings suggest that some slab sections may be more at risk than others. However, it is not known whether any of these measured values have real world implications. An initiative to develop consensus based test methods and criteria through an organization such as ASTM is recommended to determine and validate the predictive power of different measurement methods.

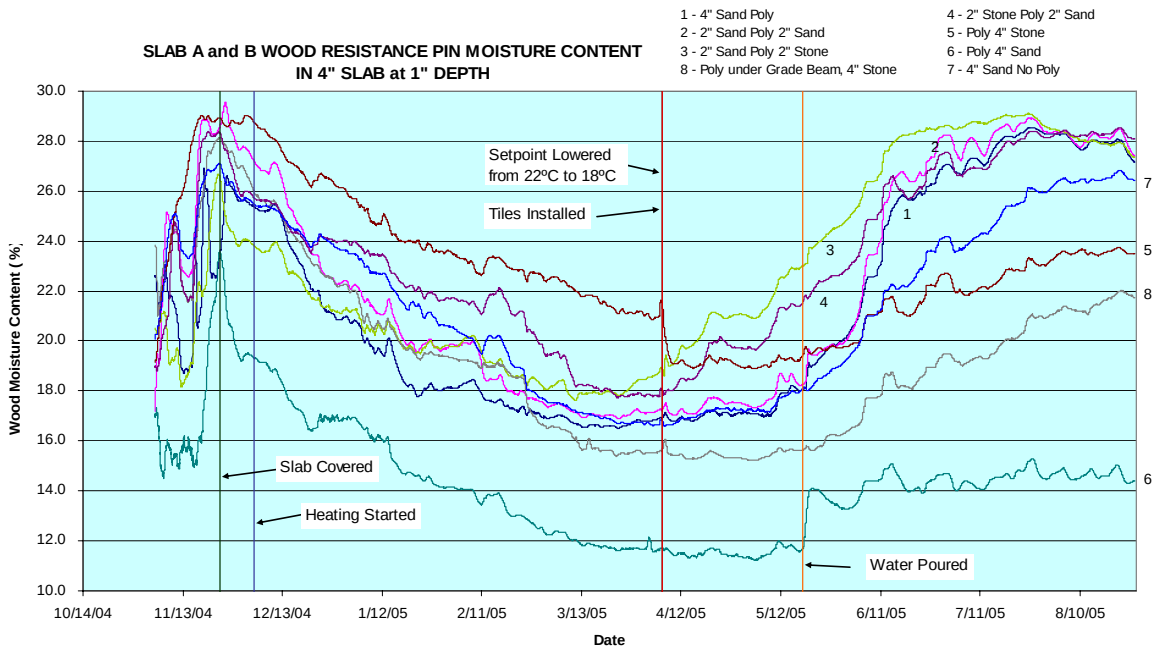

Figure 22 Slab A and B Wood Resistance Pin Moisture Content Profile in 4" Slab at 1" Depth

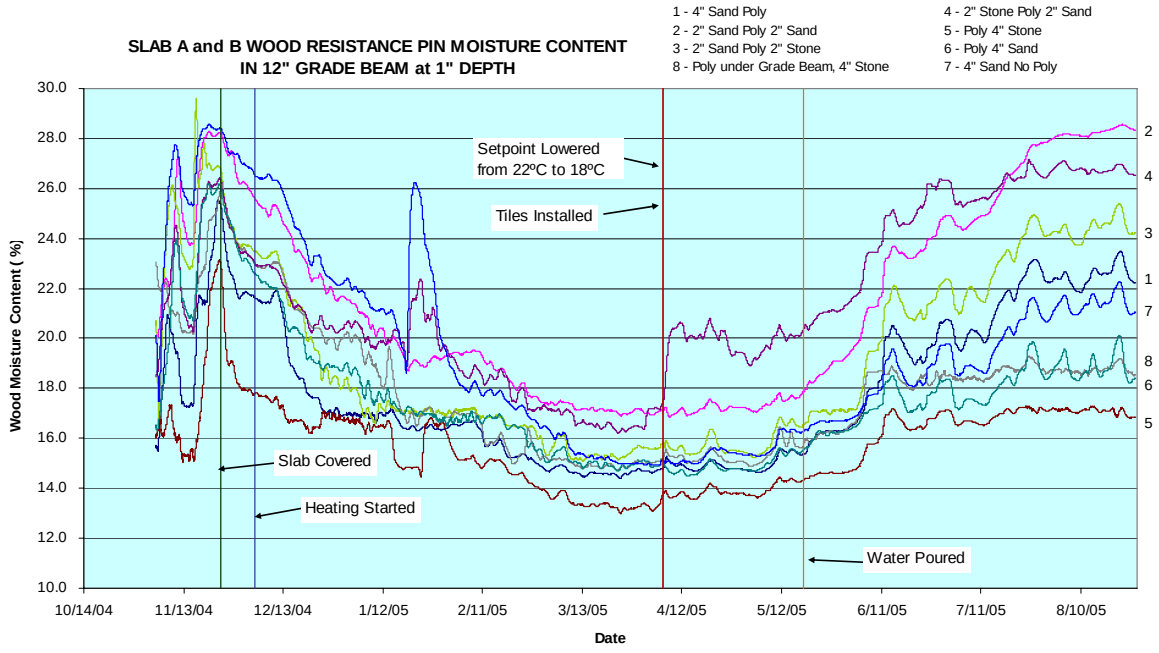

Figure 23 Slab A & B Wood Resistance Pin Moisture Content Profile, 12" Grade Beam, 1" Depth

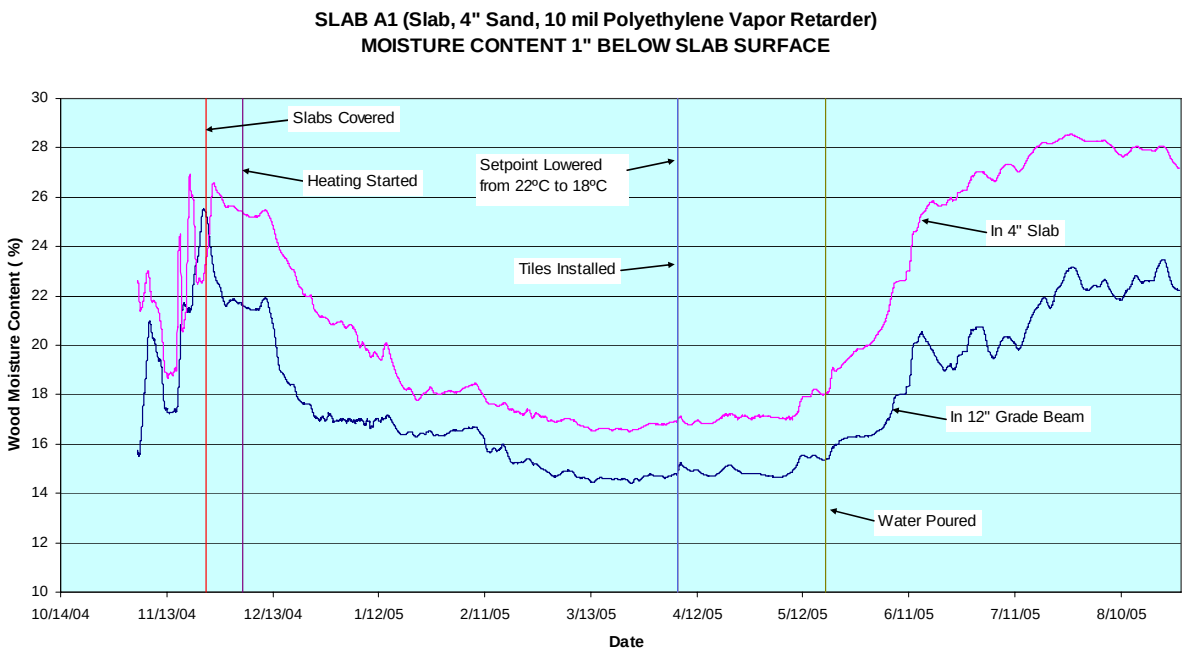

Figure 24 Slab A1 Wood Resistance Pin Moisture Content Profile

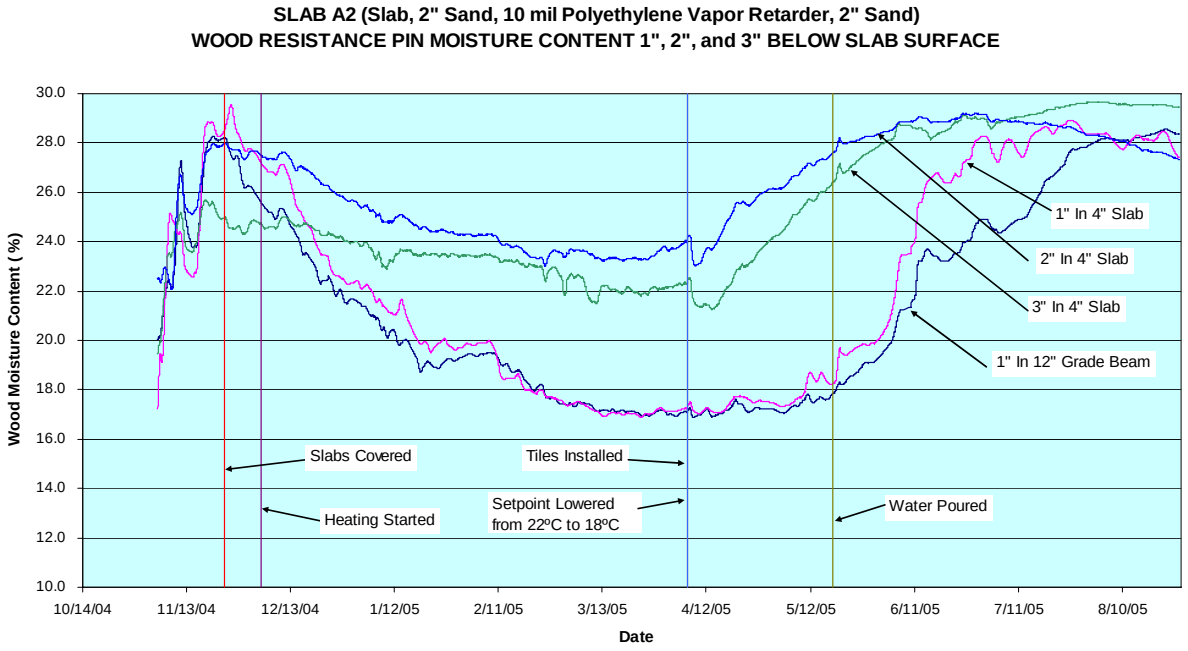

Figure 25 Slab A2 Wood Resistance Pin Moisture Content Profile

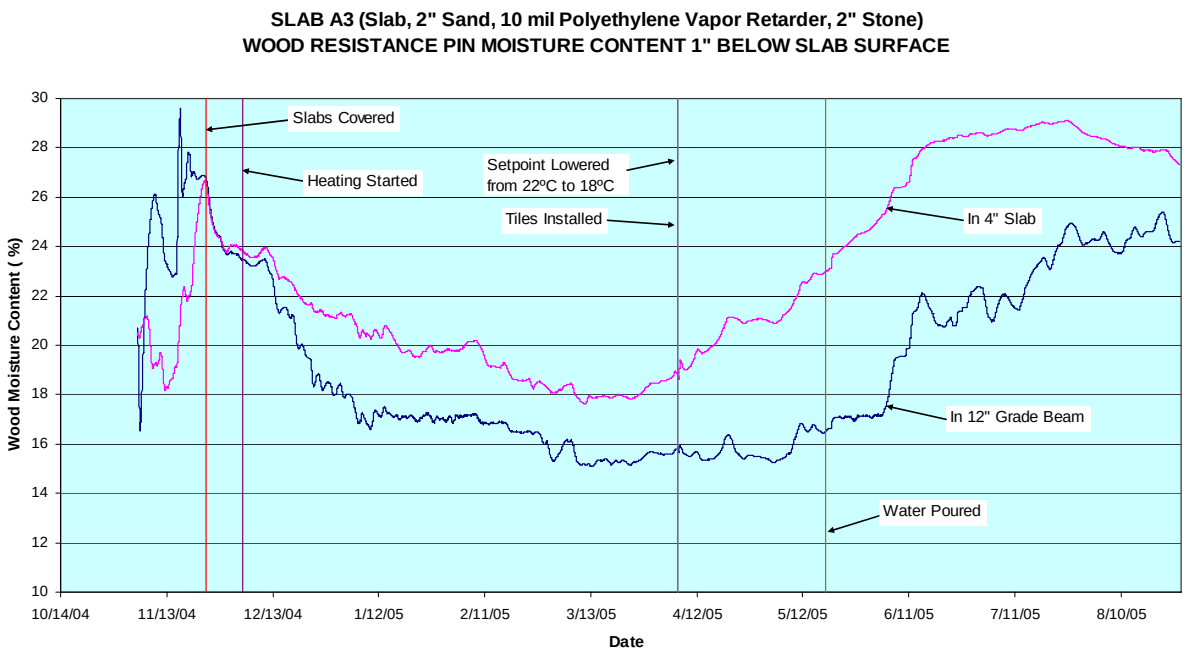

Figure 26 Slab A3 Wood Resistance Pin Moisture Content Profile

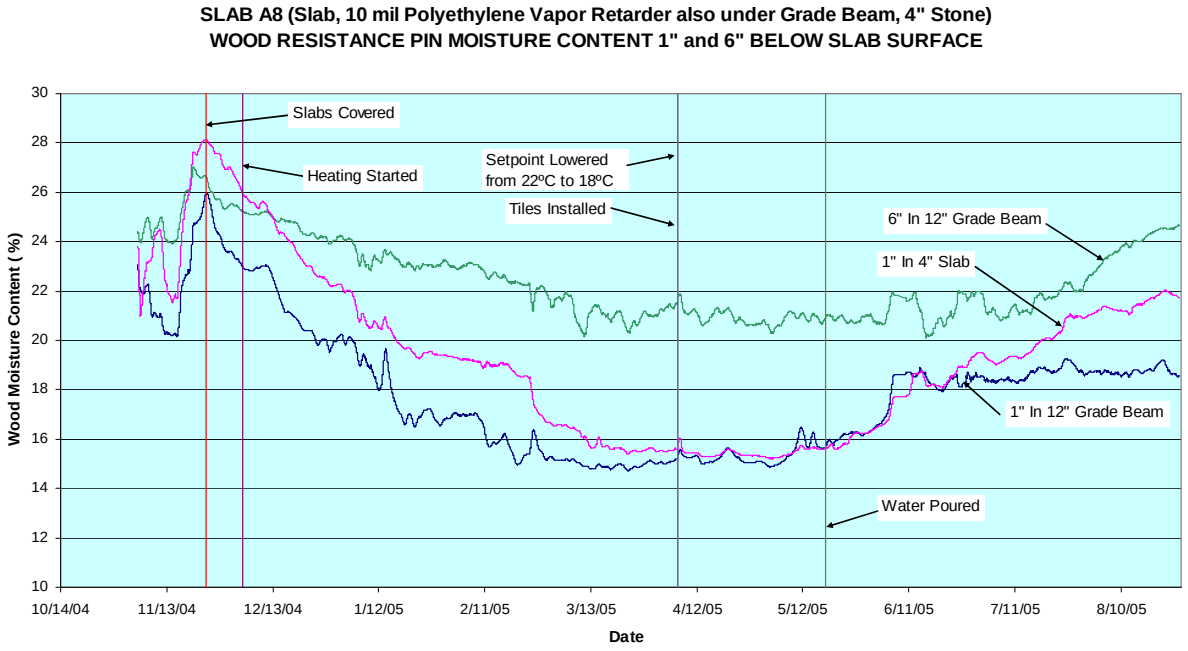

Figure 27 Slab A8 Wood Resistance Pin Moisture Content Profile

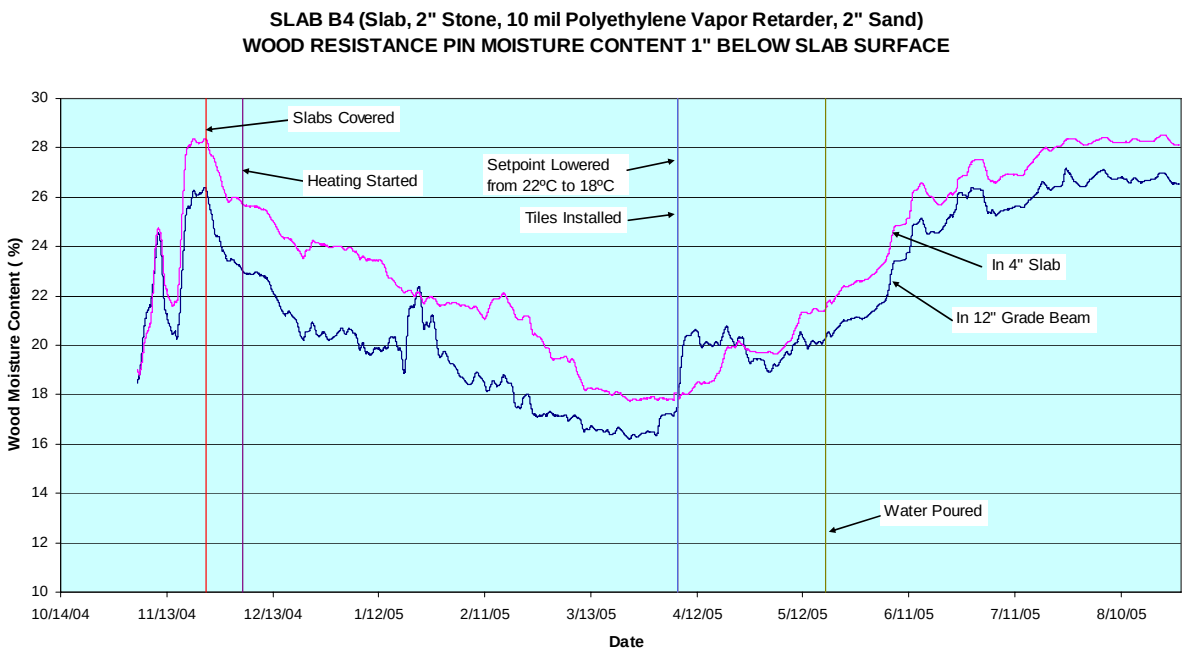

Figure 28 Slab B4 Wood Resistance Pin Moisture Content Profile

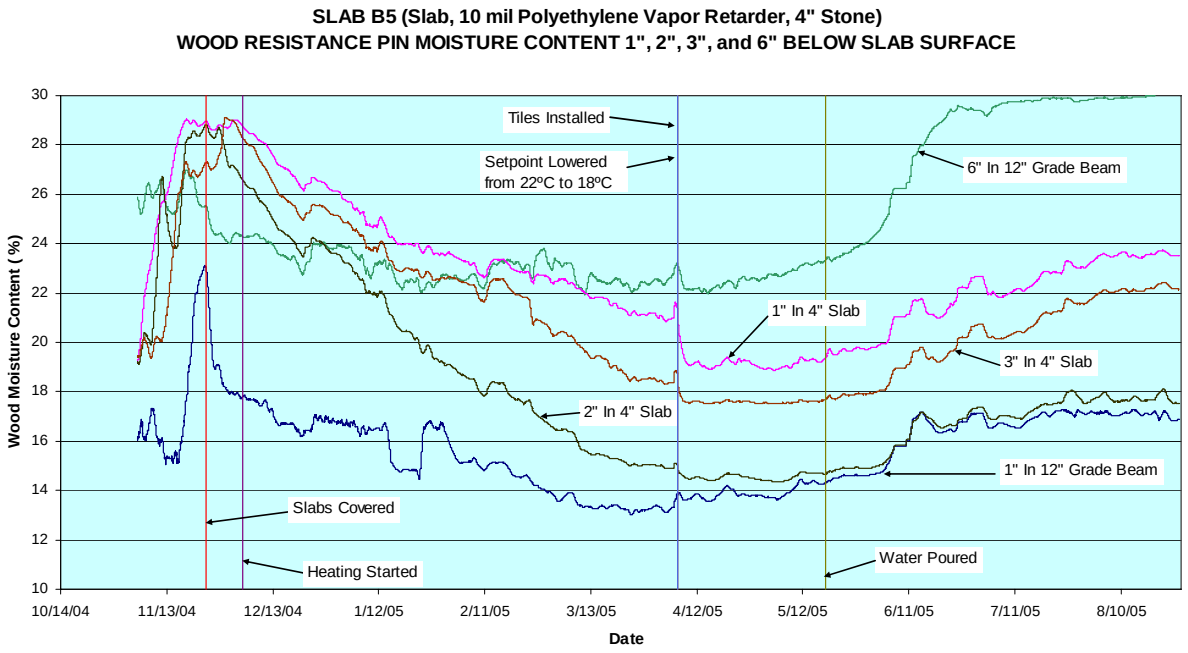

Figure 29 Slab B5 Wood Resistance Pin Moisture Content Profile

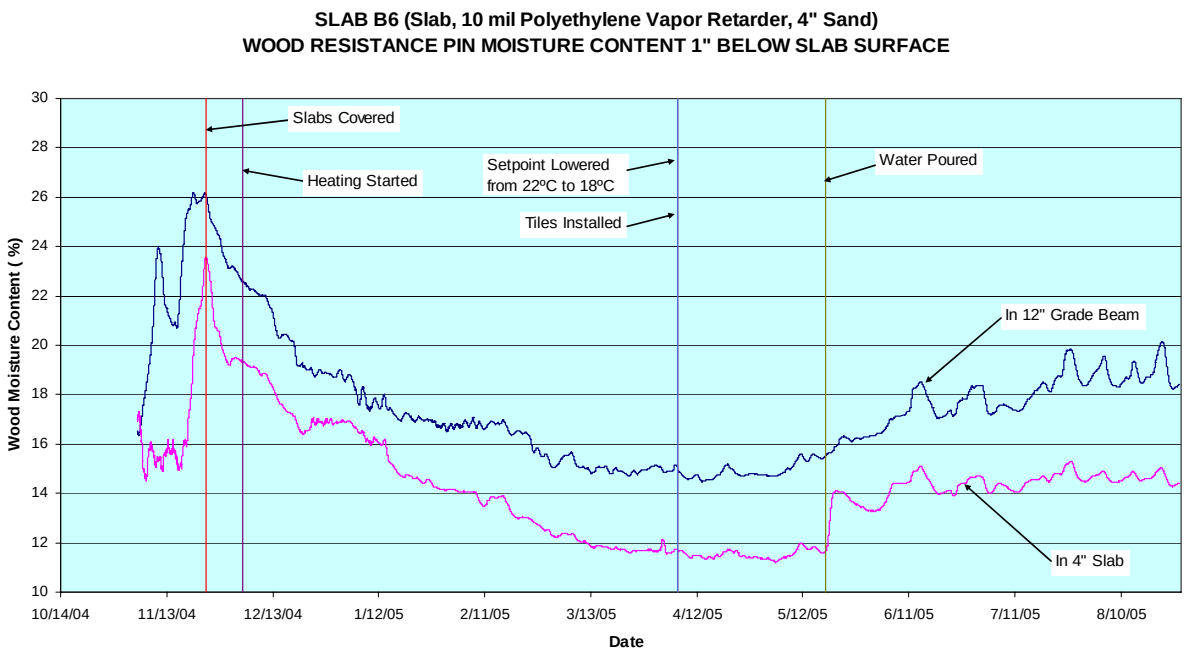

Figure 30 Slab B6 Wood Resistance Pin Moisture Content Profile

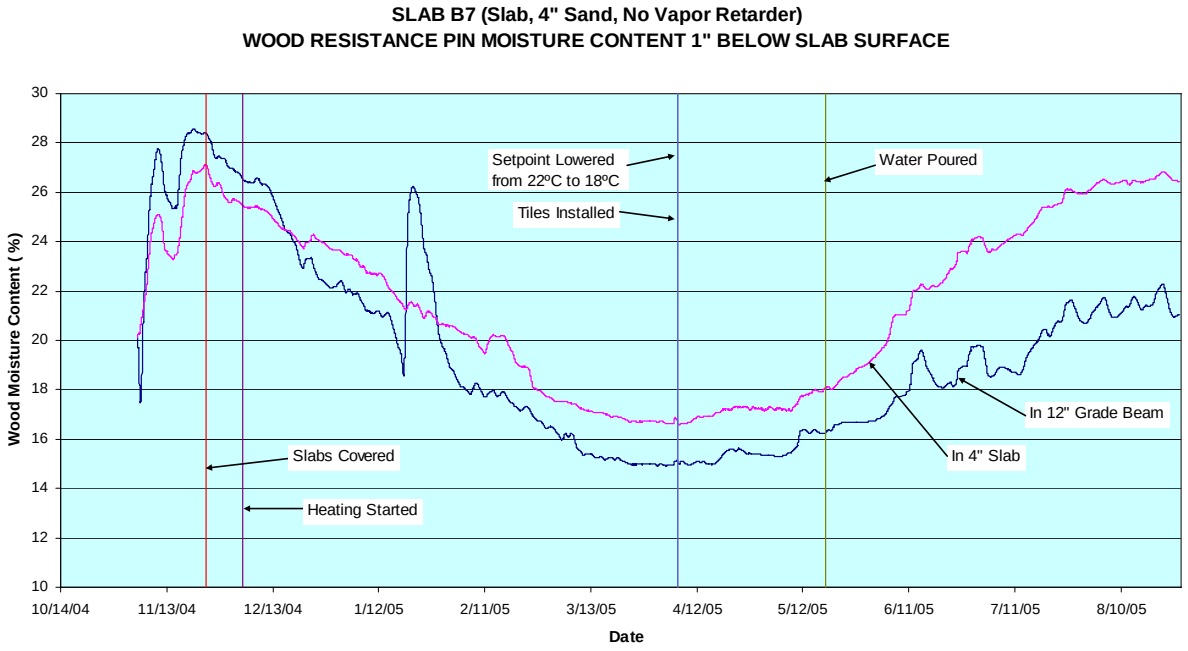

Figure 31 Slab B7 Wood Resistance Pin Moisture Content Profile

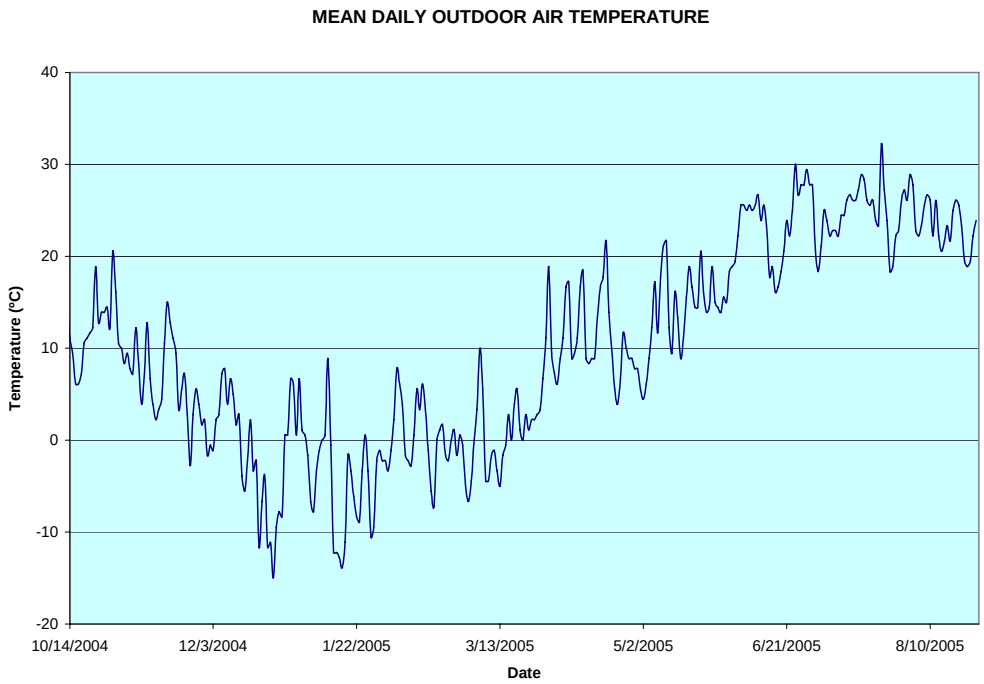

Figure 32 Outdoor Air Temperature Profile

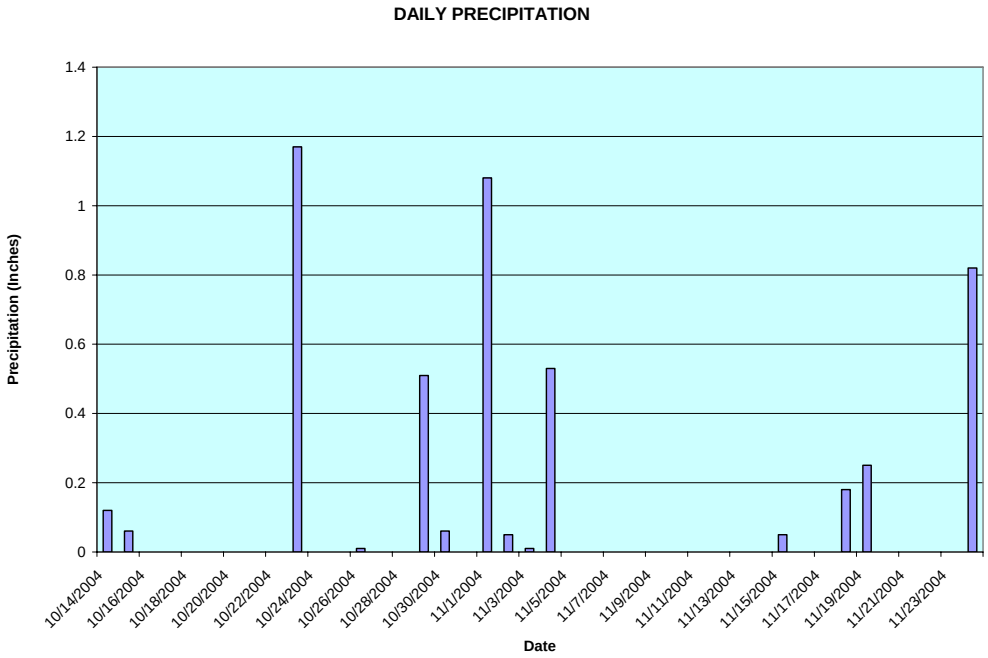

Figure 33 Daily Precipitation 10/14/04 through 11/24/04

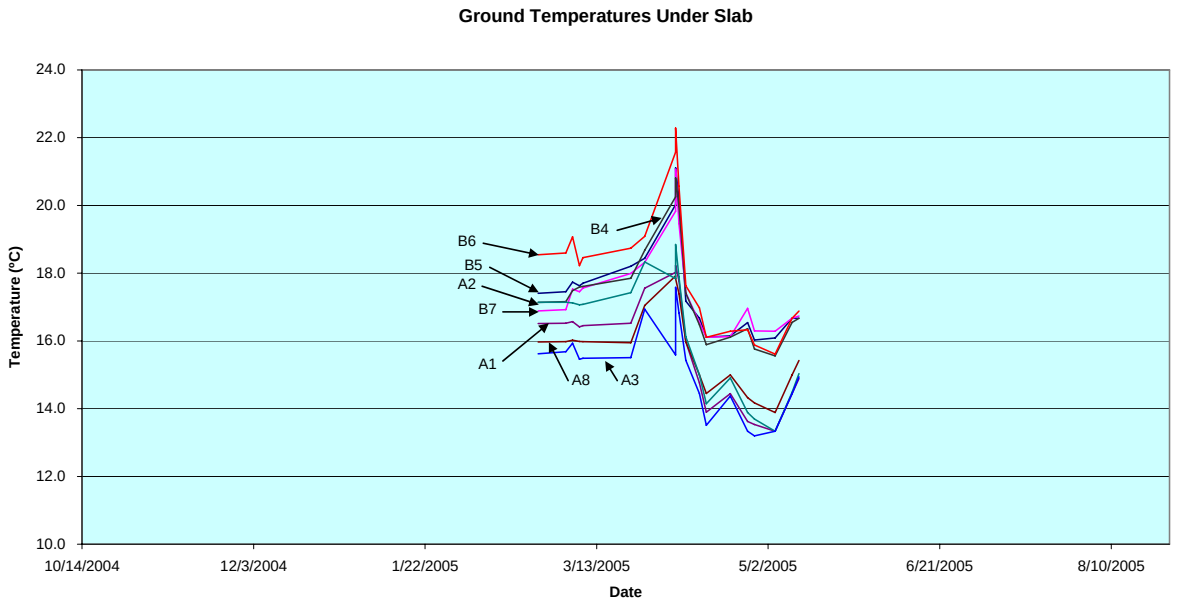

Figure 34 Soil Temperatures 6" Below Slabs A and B

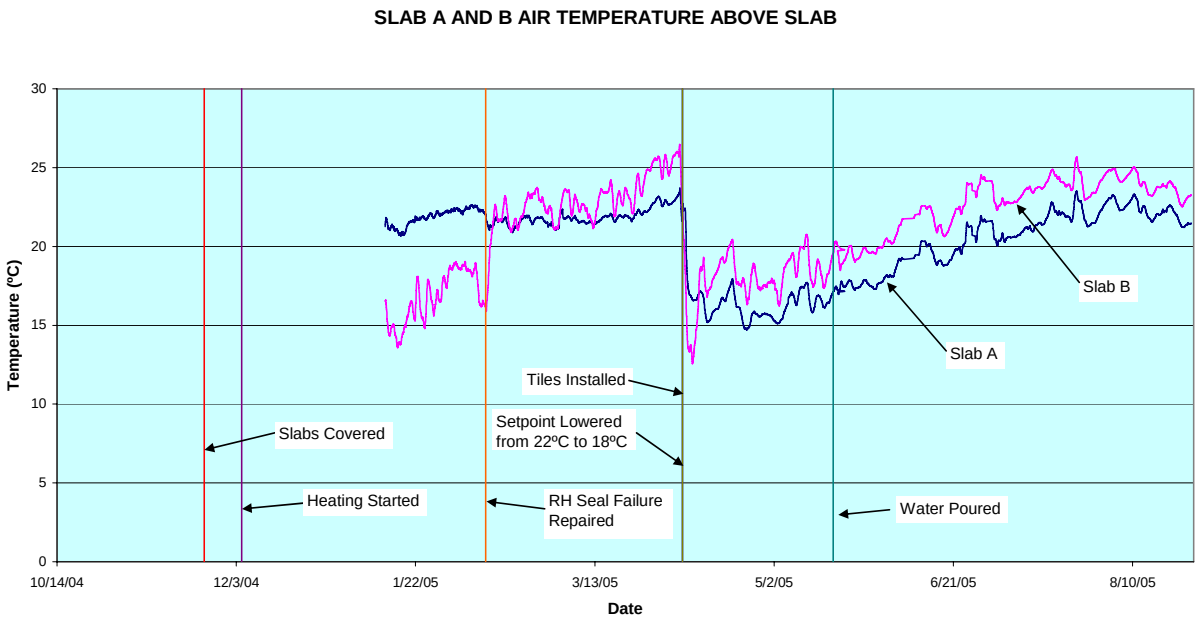

Figure 35 Air Temperature in Enclosure Above Slabs A and B

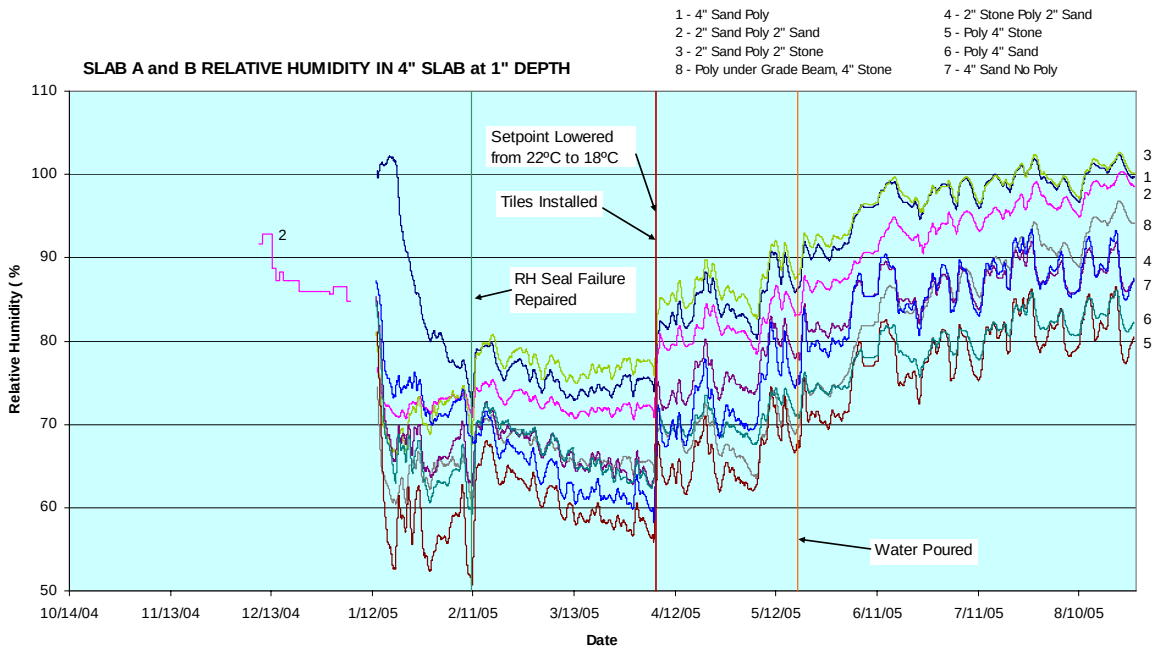

Figure 36 Slab A and B Relative Humidity Profile in 4" Slabs at 1" Depth

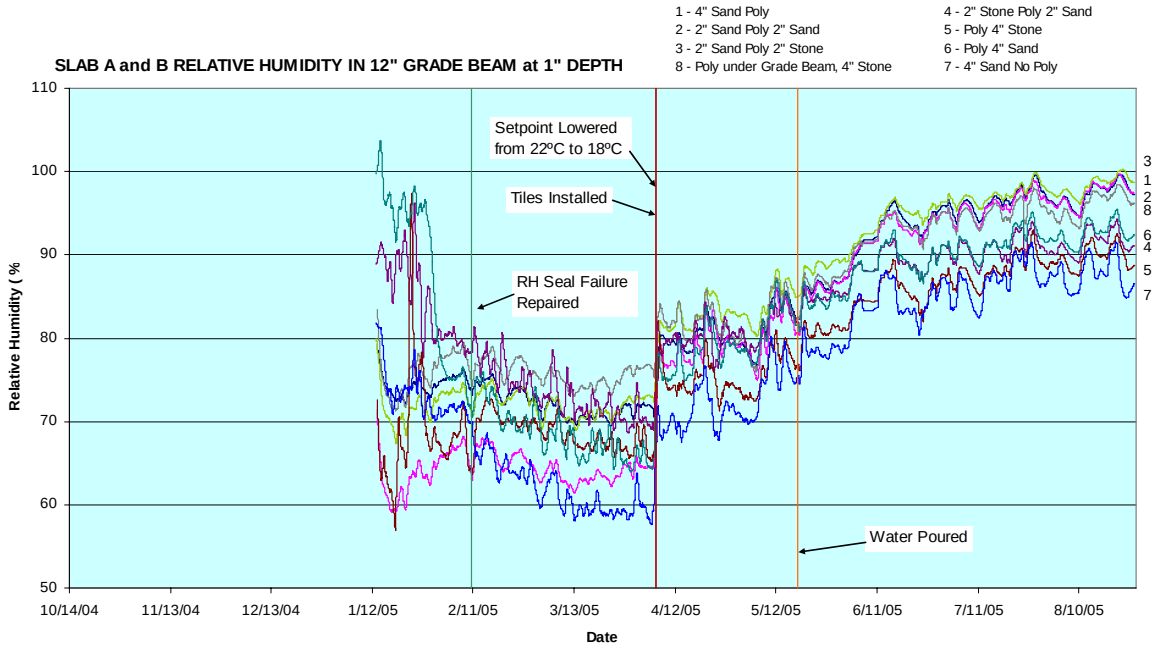

Figure 37 Slab A and B Relative Humidity Profile in 12" Grade Beam at 1" Depth

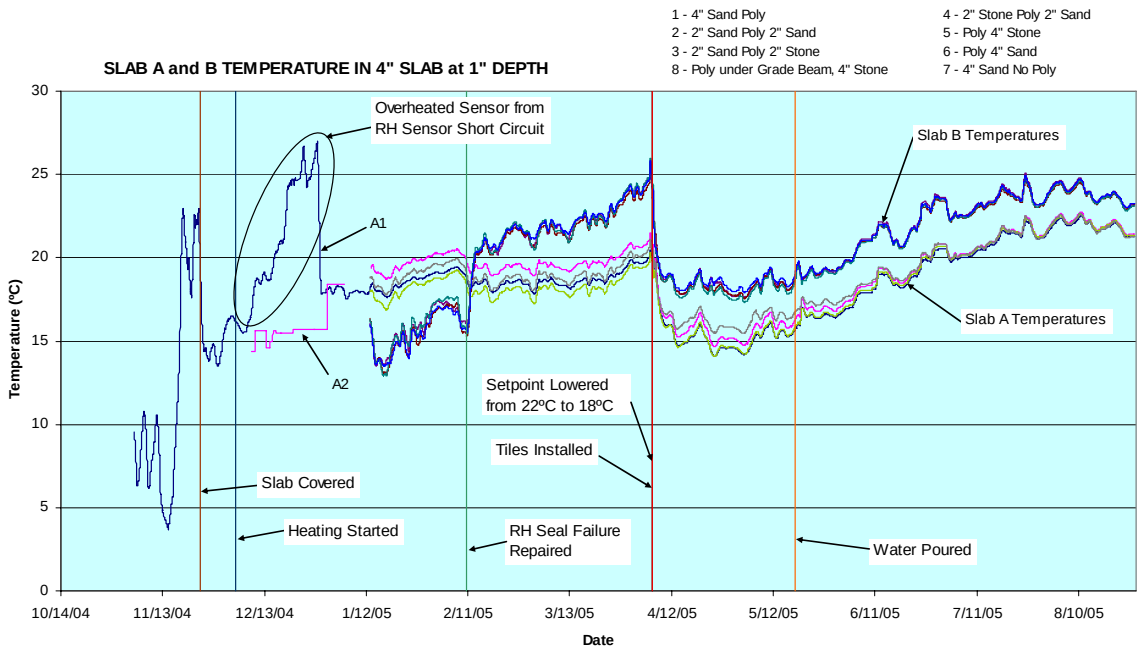

Figure 38 Slab A and B Air Temperature Profile in 4" Slabs at 1" Depth

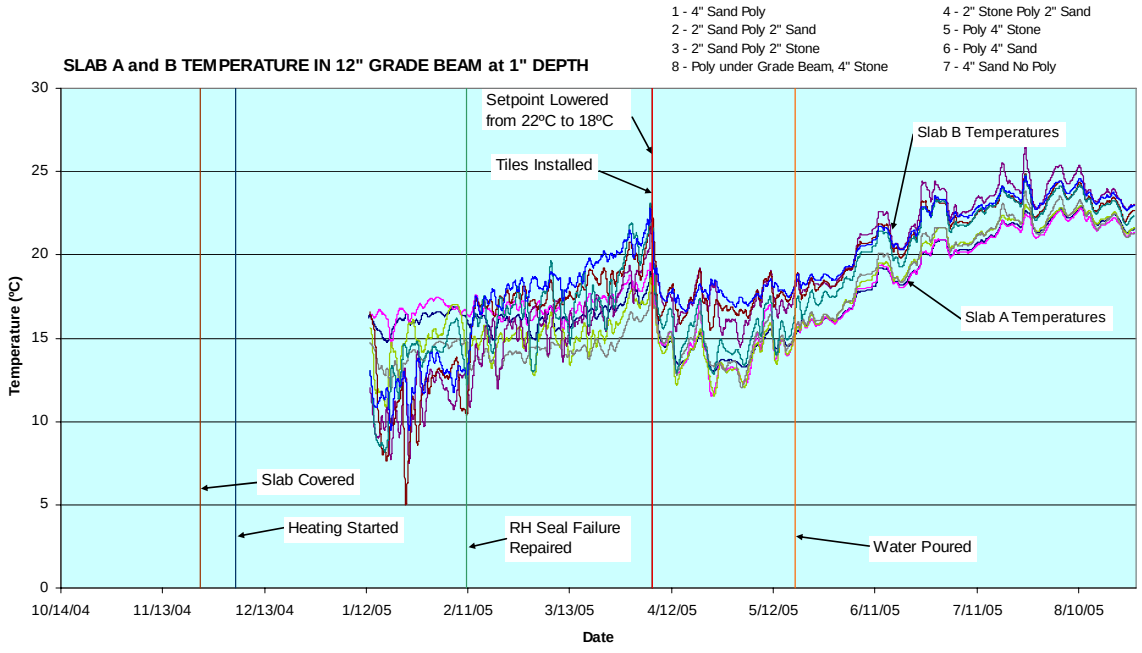

Figure 39 Slab A and B Air Temperature Profile in 12" Grade Beam at 1" Depth

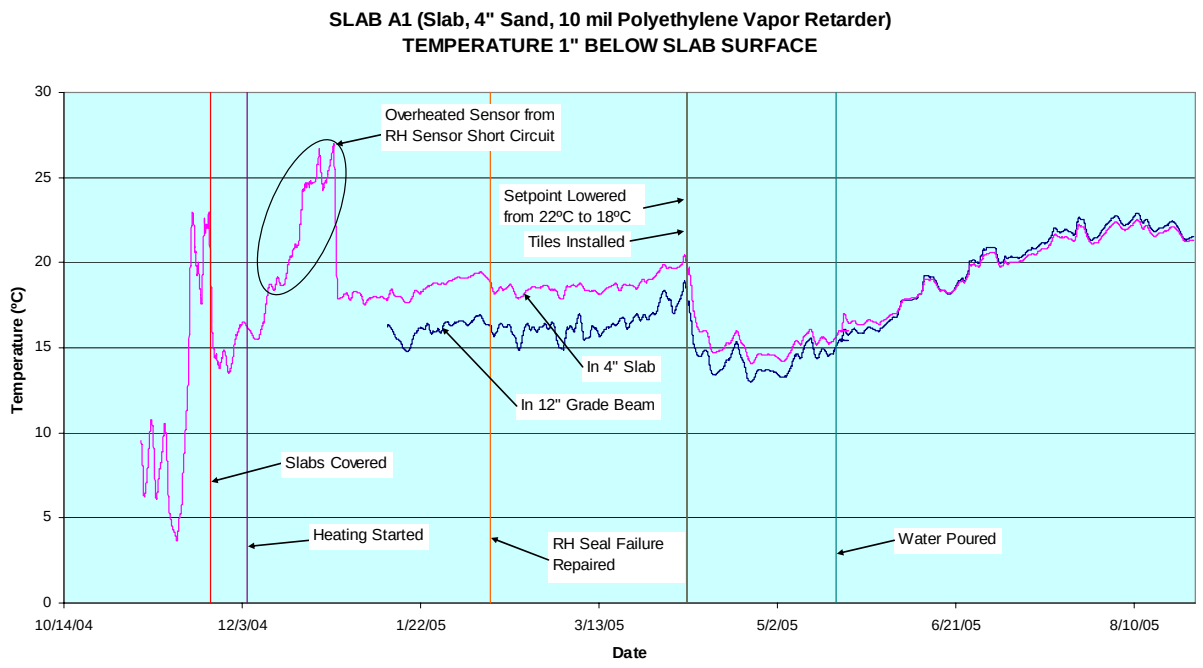

Figure 40 Slab A1 Temperature Profile

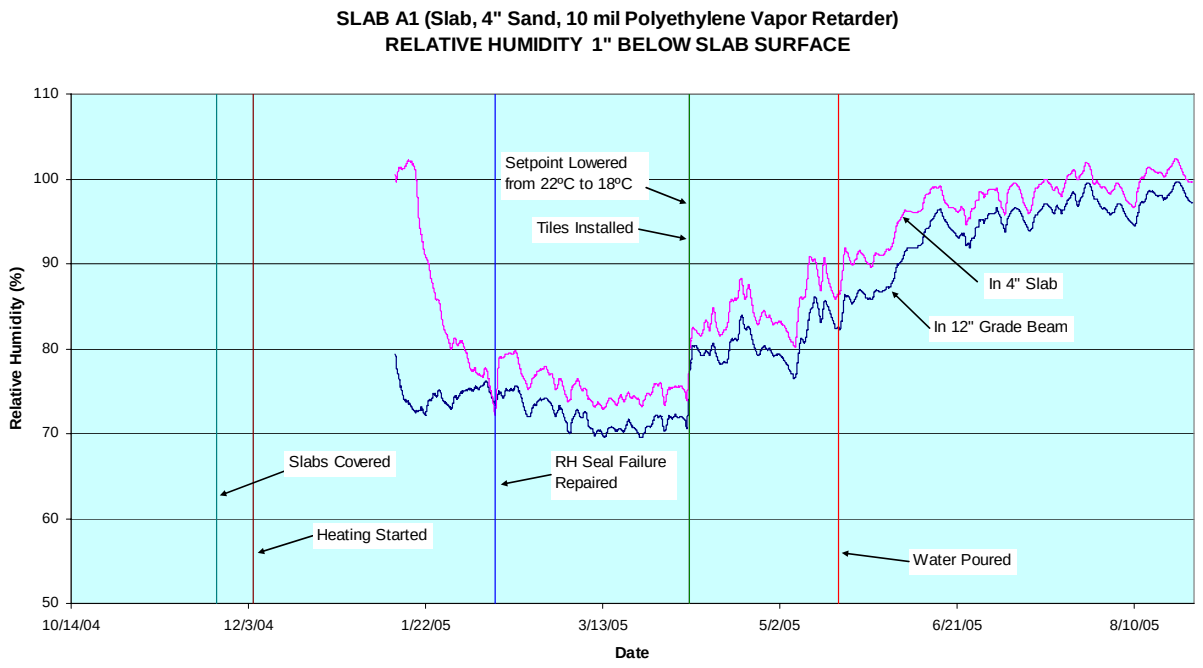

Figure 41 Slab A1 Relative Humidity Profile

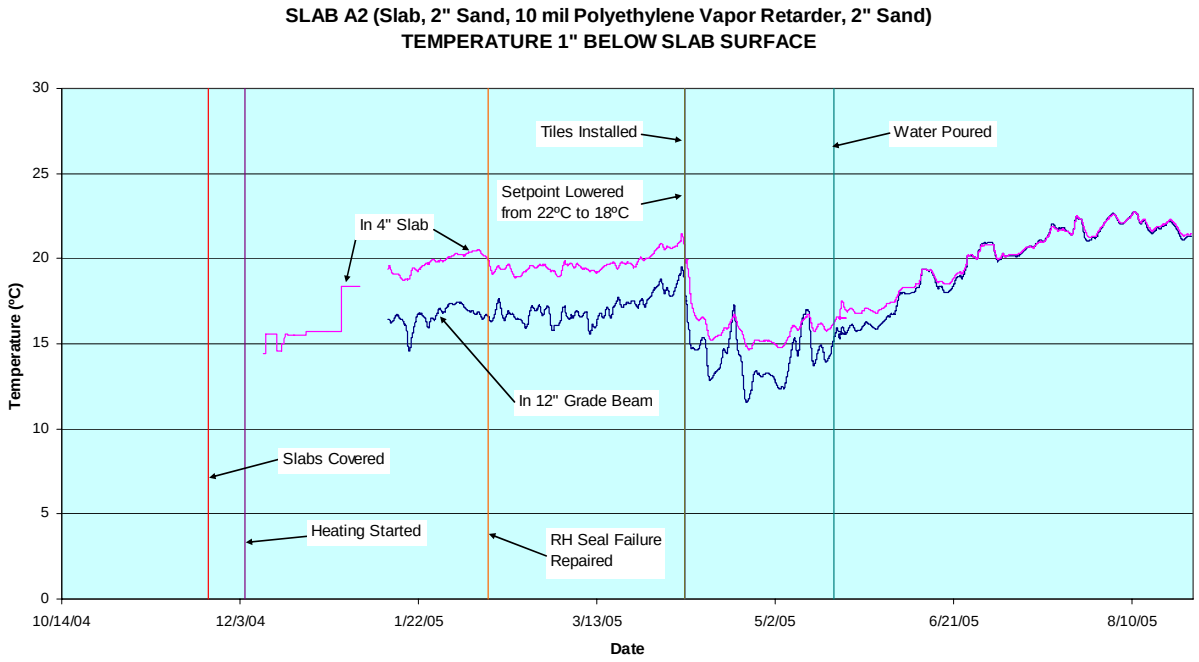

Figure 42 Slab A2 Temperature Profile

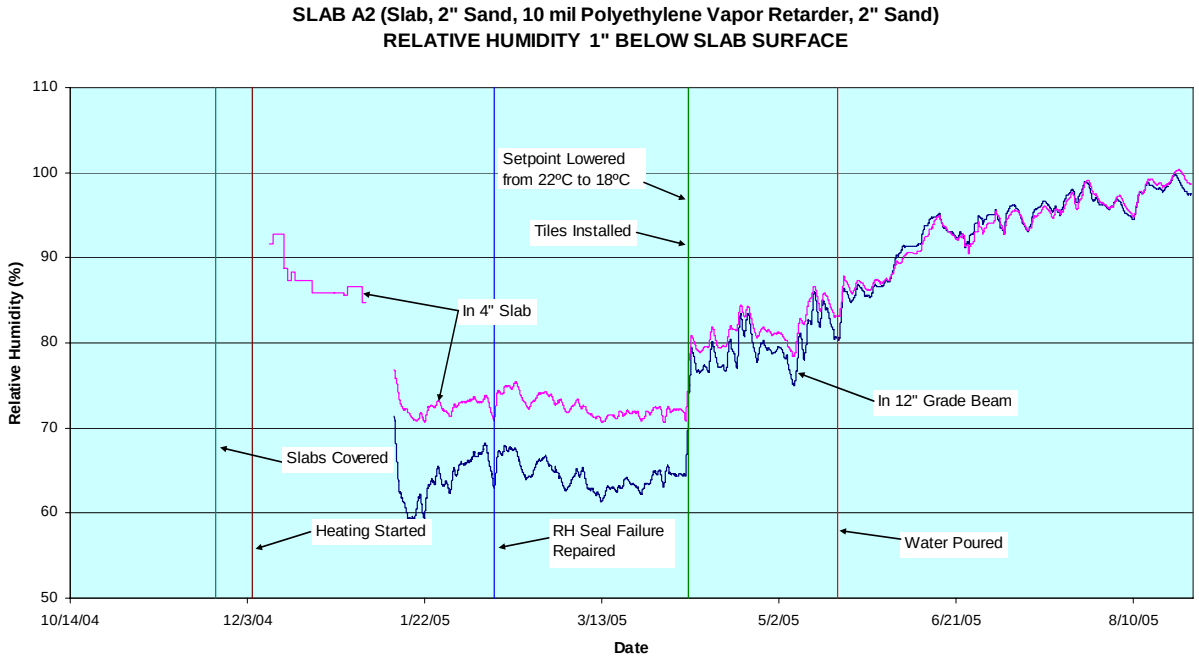

Figure 43 Slab A2 Relative Humidity Profile

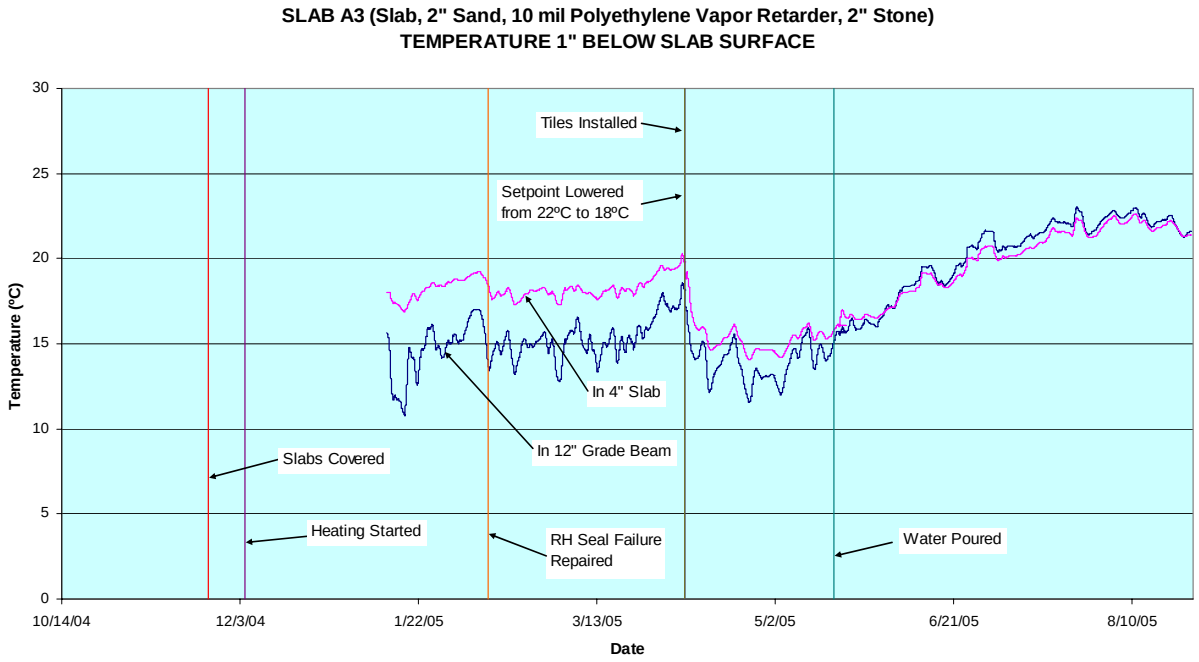

Figure 44 Slab A3 Temperature Profile

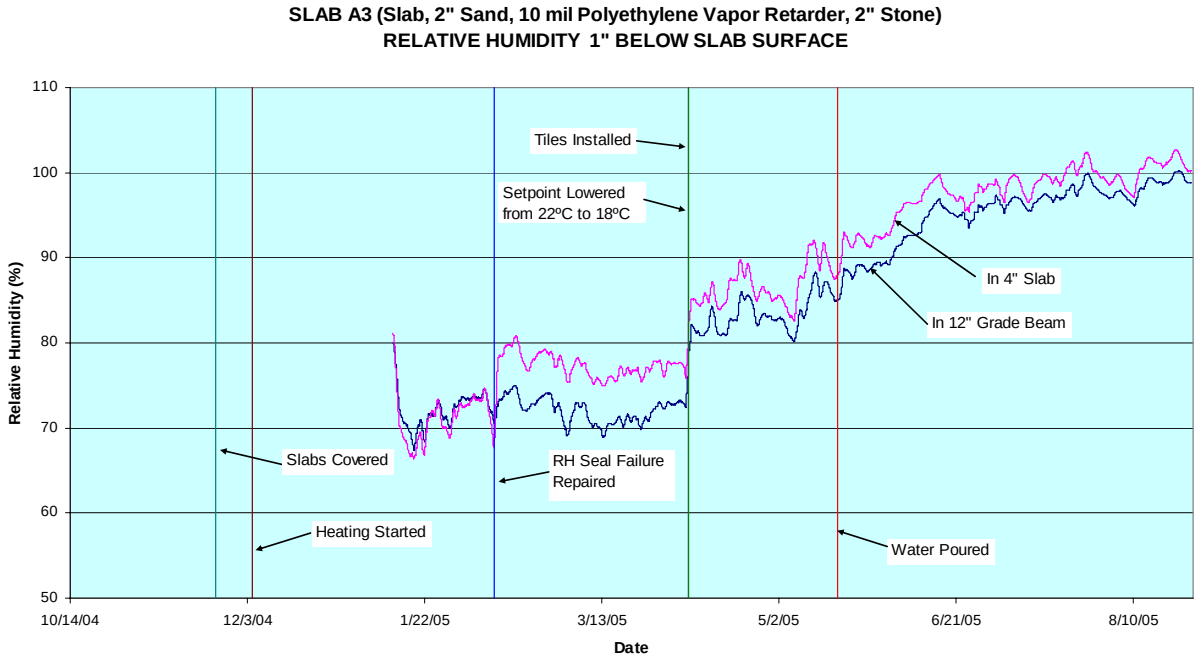

Figure 45 Slab A3 Relative Humidity Profile

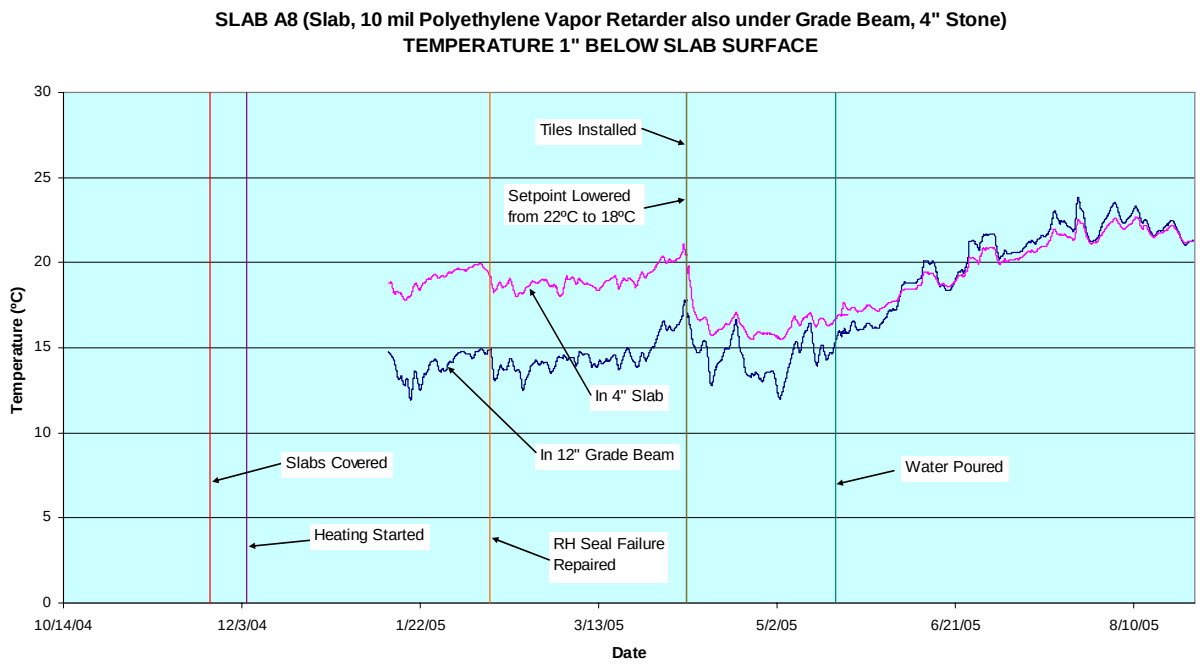

Figure 46 Slab A8 Temperature Profile

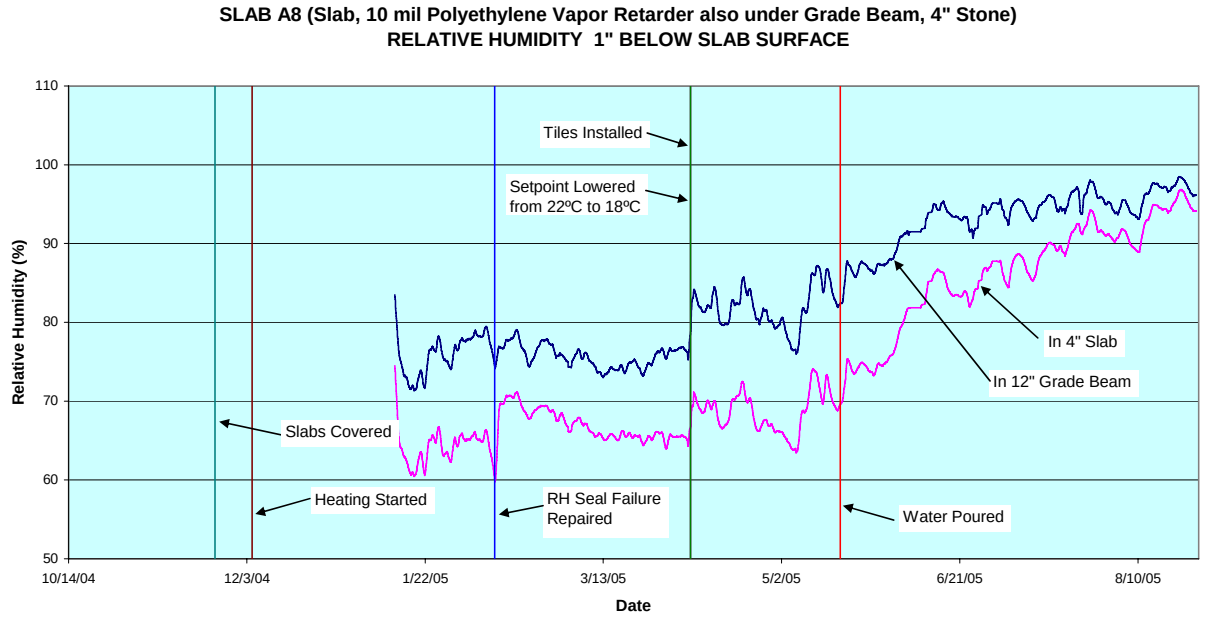

Figure 47 Slab A8 Relative Humidity Profile

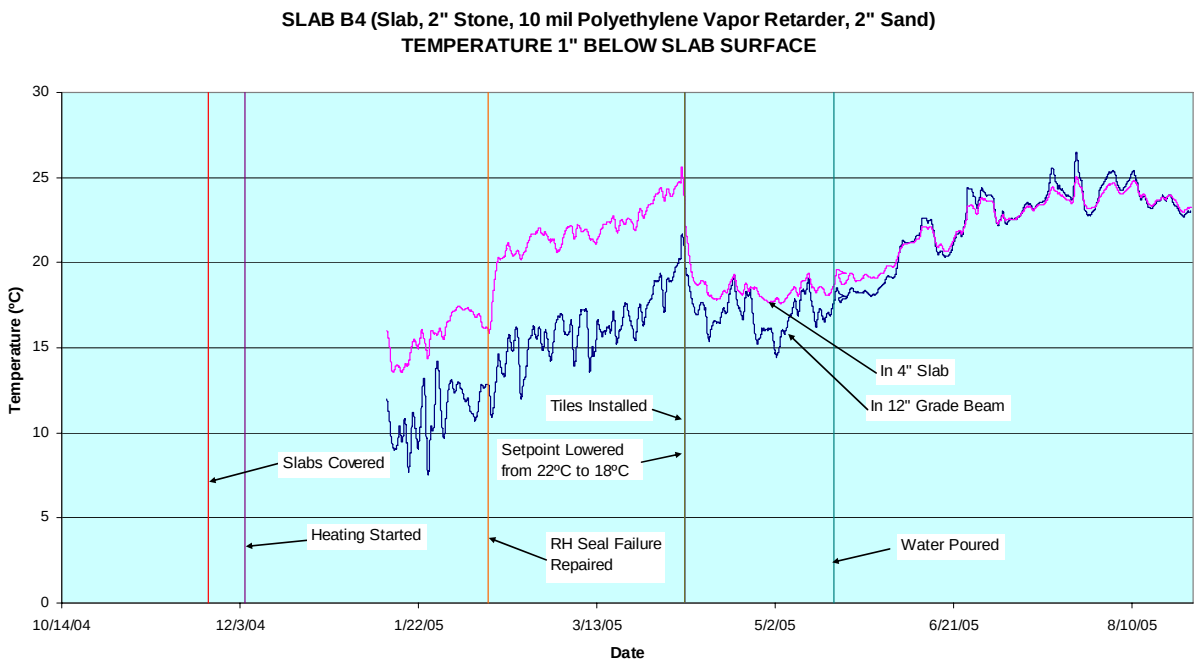

Figure 48 Slab B4 Temperature Profile

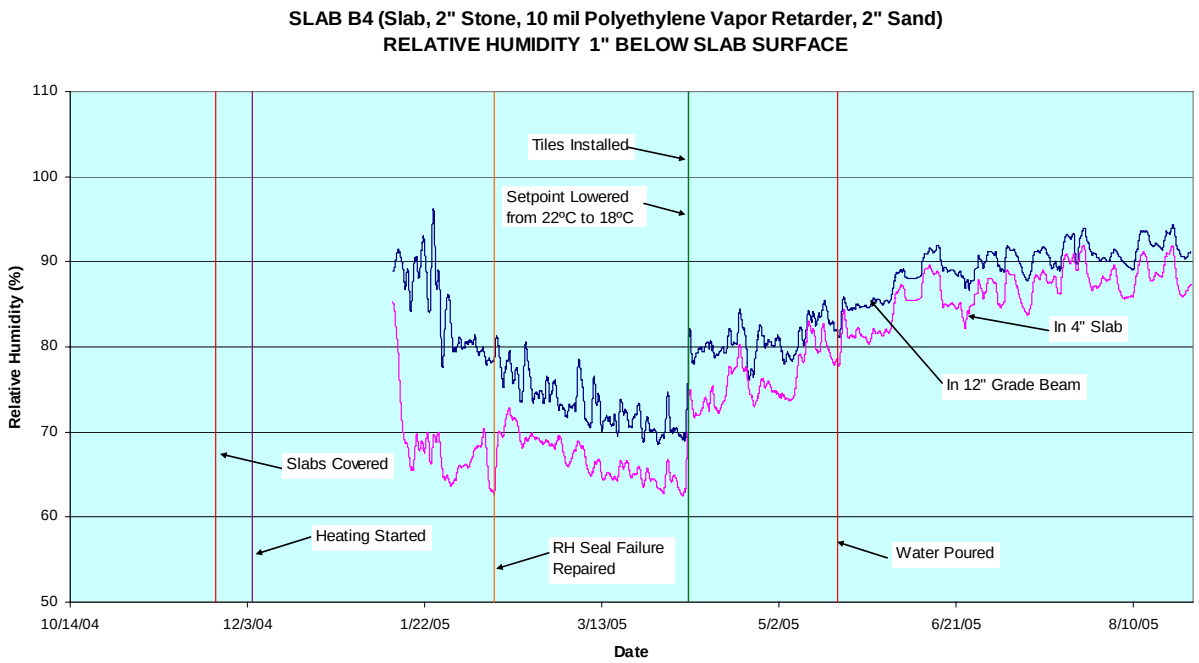

Figure 49 Slab B4 Relative Humidity Profile

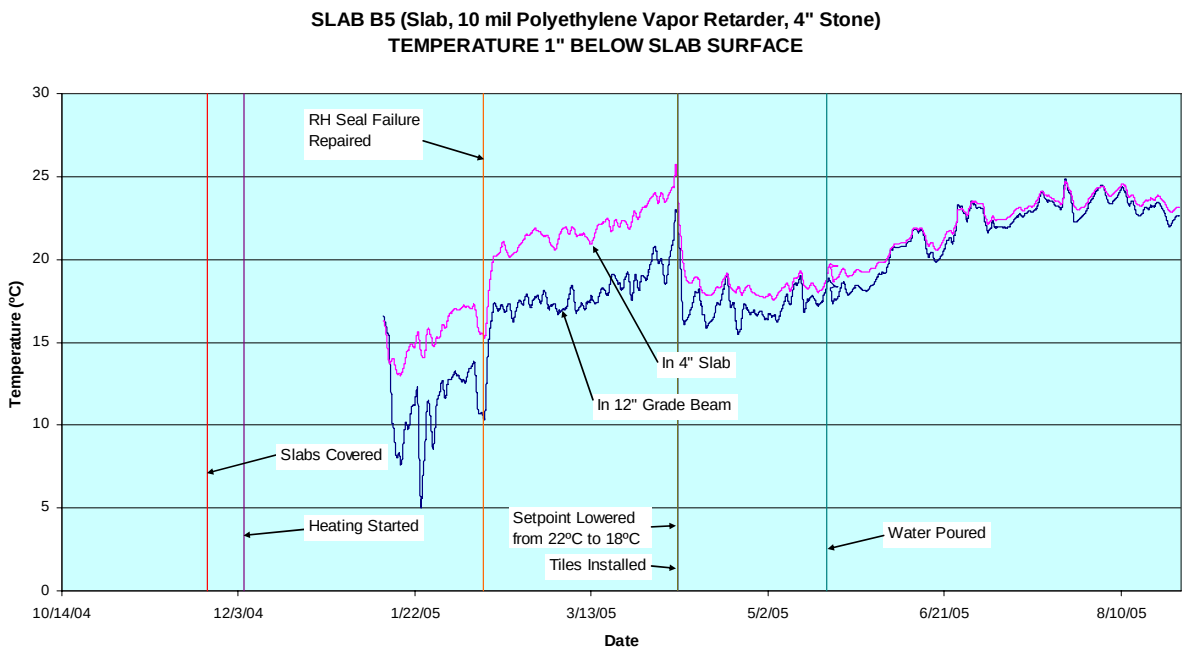

Figure 50 Slab B5 Temperature Profile

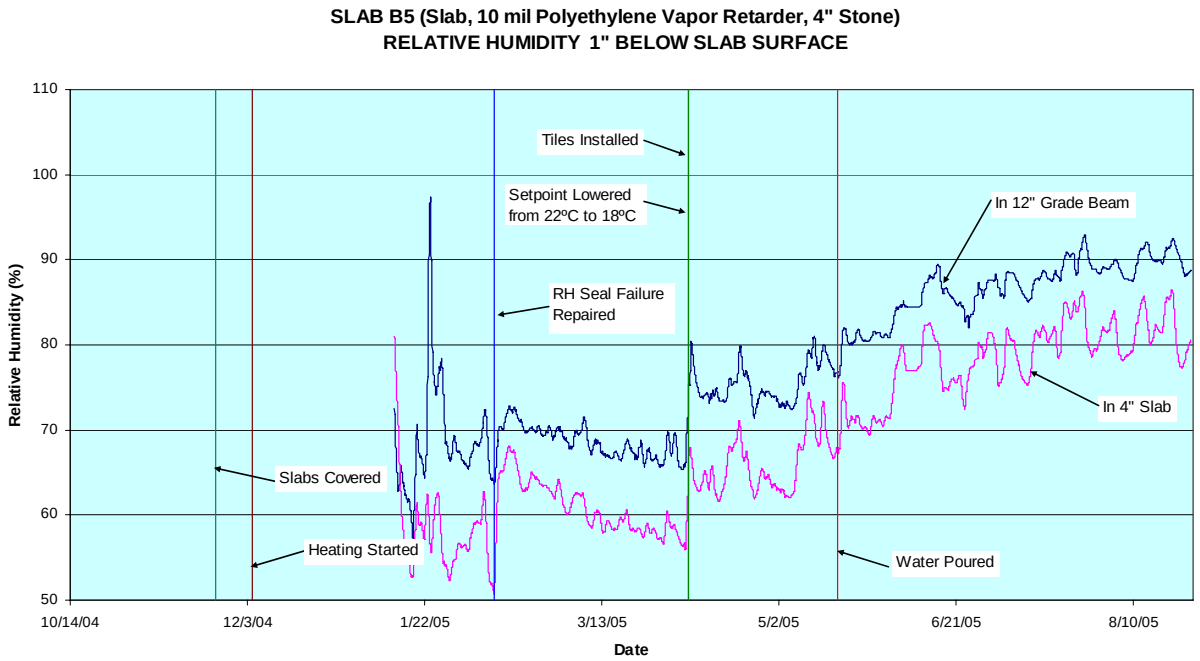

Figure 51 Slab B5 Relative Humidity Profile

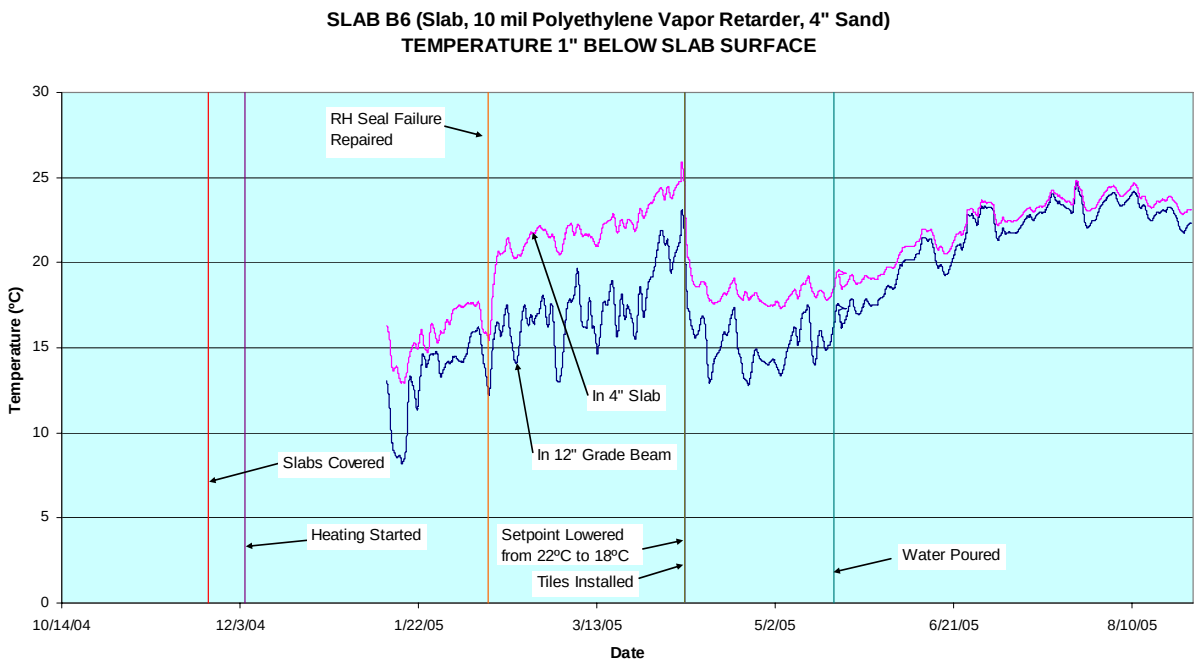

Figure 52 Slab B6 Temperature Profile

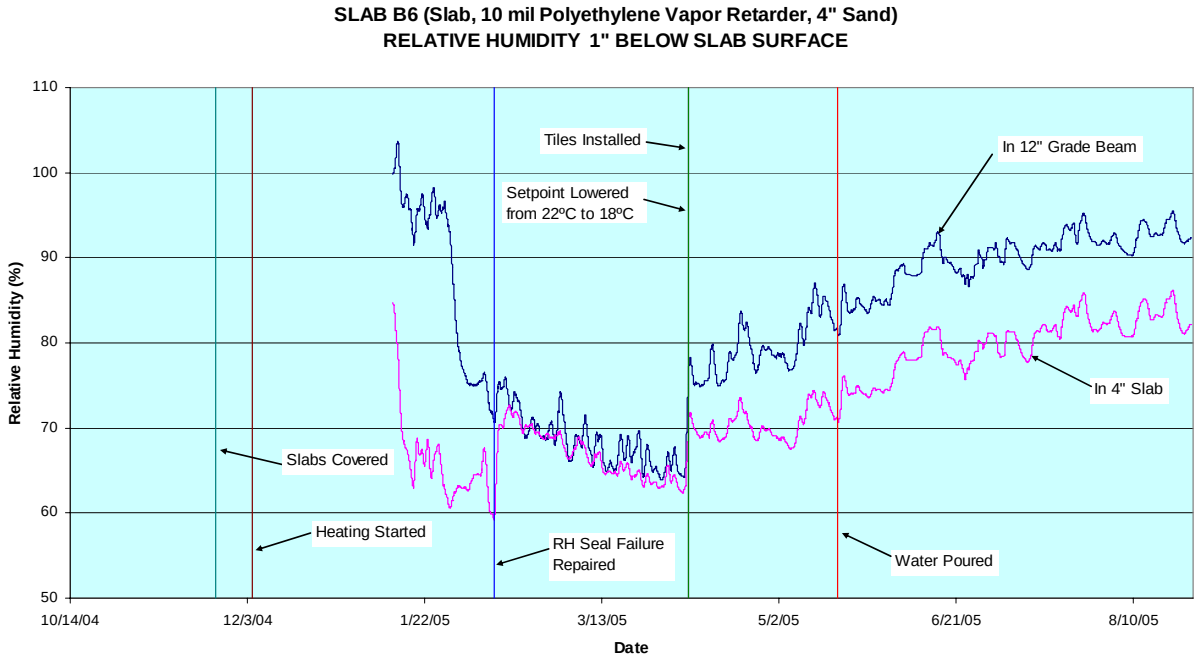

Figure 53 Slab B6 Relative Humidity Profile

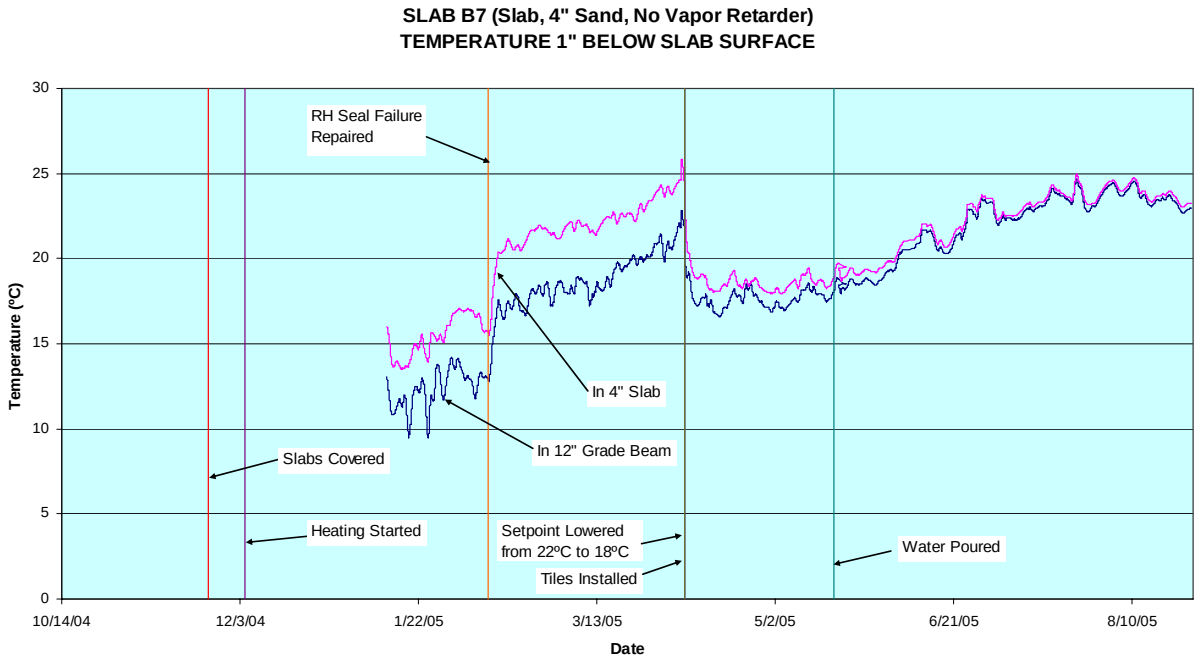

Figure 54 Slab B7 Temperature Profile

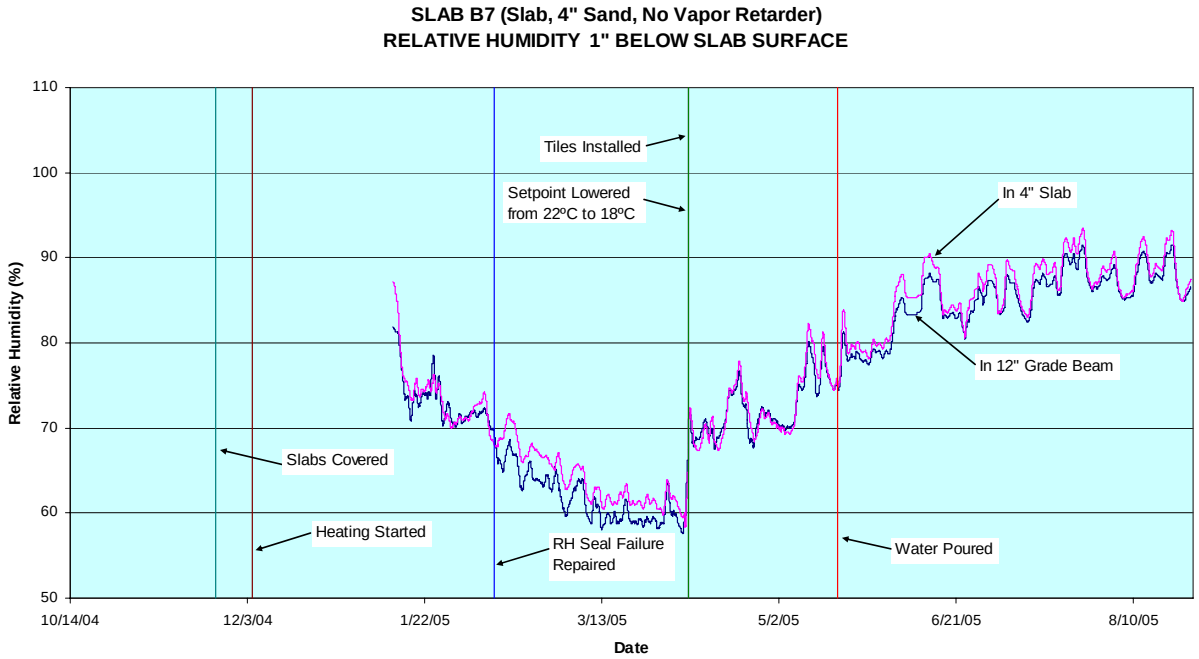

Figure 55 Slab B7 Relative Humidity Profile

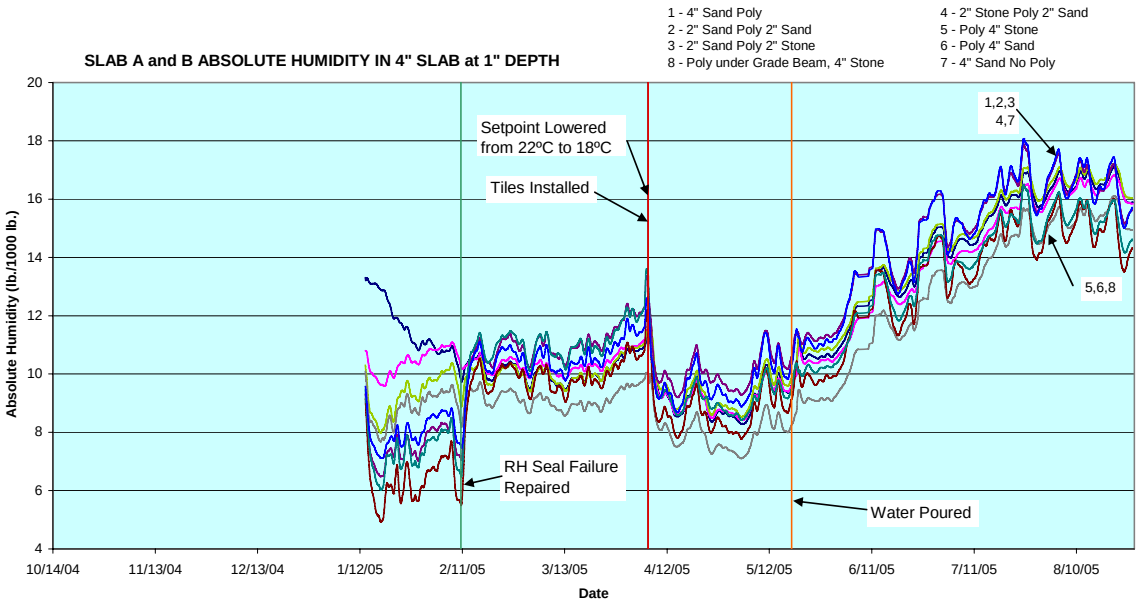

Figure 56 Slab A and B Absolute Humidity Profile in 4" Slabs at 1" Depth

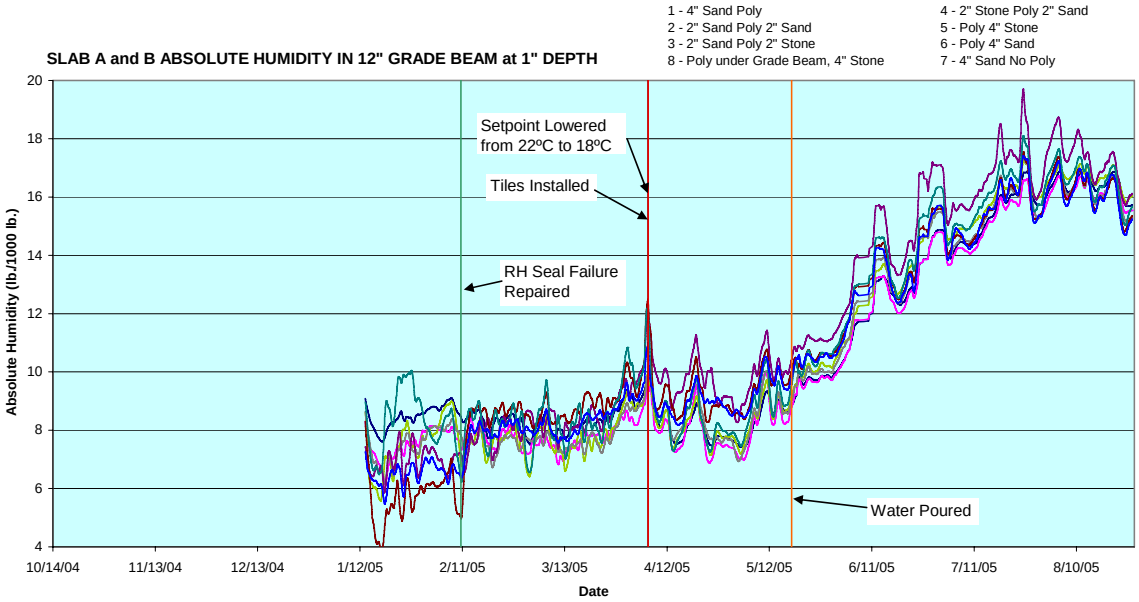

Figure 57 Slab A and B Absolute Humidity Profile in 12" Grade Beam at 1" Depth

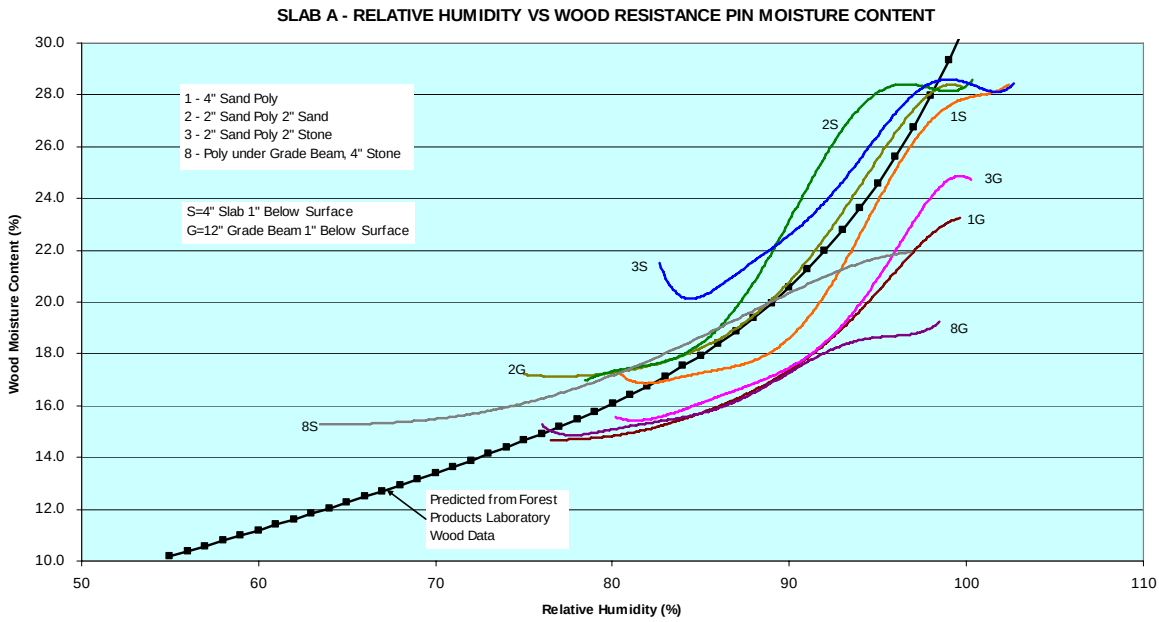

Figure 58 Slab A Relative Humidity vs. Wood Resistance Pin Moisture Content

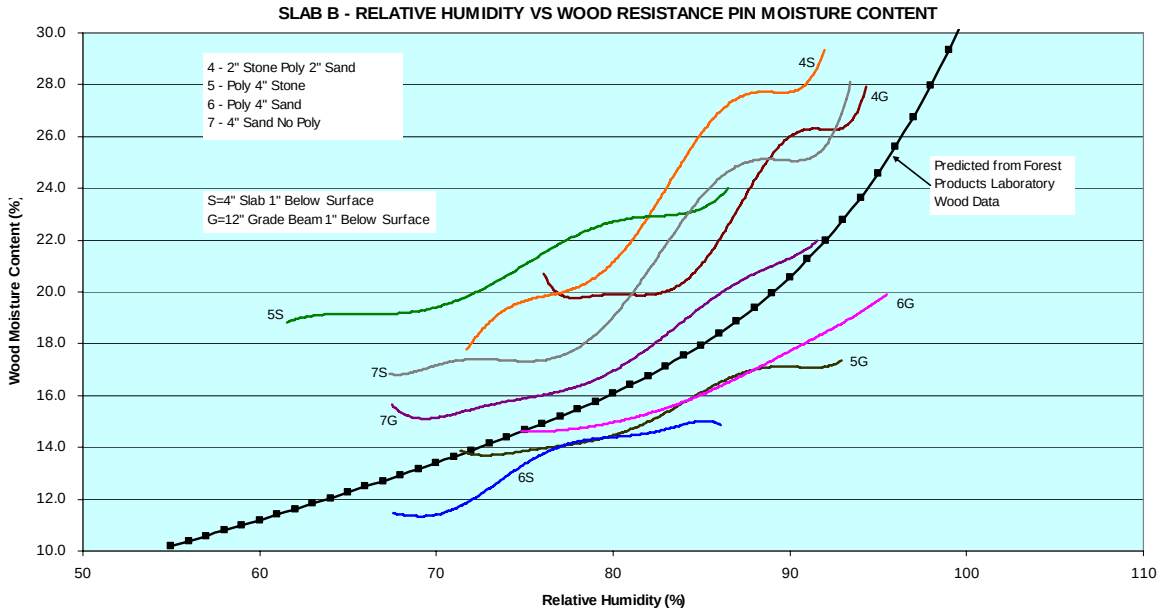

Figure 59 Slab B Relative Humidity vs. Wood Resistance Pin Moisture Content