Testing the Flood Resiliency of Historic Exterior Wall Systems, Plaster Using Test Protocol BRS 2-22

Protocol 2 Report

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BUILDING RESILIENT SOLUTIONS

MUSEUM RESOURCES CONSTRUCTION & MILLWORK

COMMONWEALTH PRESERVATION GROUP

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TABLE OF CONTENTS

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1. PURPOSE

This report documents the methodology, results, and conclusions of testing undertaken by Building Resilient Solutions (BRS) to study the survivability of historic plaster wall assemblies and exterior cladding materials that have been exposed to limited duration water inundation, as is commonly experienced during tidal flooding events. Specifically, this testing was designed to evaluate traditional historic taper sawn wood siding with plaster on wood lath and plaster on wire lath. An additional test sample composed of modern wall materials, insulation, and drywall was also included to compare the performance of modern materials against the traditional historic materials. These tests followed "BRS Protocol 2-22, Test Protocol for Flood Testing of Exterior Wall Systems" which was developed by Georg Reichard, Ph.D., P.E. for BRS. "BRS 2-22" was designed to create a consistent assessment method regarding the durability and re-workability of wall assemblies after flooding events and adopted processes from various related standards to make them applicable for the testing of specific assemblies in a controlled flood event and an environmentally controlled test chamber. Specifically, this testing was intended to replicate flood events and drying periods typical to the conditions seen in Tidewater, Virginia to analyze their affect on exterior wood cladding, plaster, and lath applied using traditional historic methods and materials. The consistent testing methods and observations made during this test cycle will establish a replicable means of testing the survivability of historic wall assembly materials during a flood event, as well as an assessment of the effect of drying processes on materials.

The testing examined four principal areas of potential damage to wall assemblies:

1. To determine the impact on the plaster's ability to remain adhered to the wall system and the lath after a flood event and drying.
2. To determine the changes in the mechanical properties of each wall assembly as related to both interior and exterior finishes after a flood event and drying.
3. To determine the impact of flooding and drying on taper sawn wood siding.
4. To determine the re-workability of the material and the extent of work required to re-use the finishes after a flood event and drying.

This testing was not intended to address all possible flooding scenarios. The purpose was to examine the effects of controlled flooding and drying cycles on one modern and several historic wall systems.

2. TEST METHODS

2.1 MATERIALS FOR TESTING

Testing was performed using historic materials typical of pre-1940 construction in Tidewater Virginia and the modern materials that have replaced them in more recent construction. Samples were selected based on species, composition, and application methods. Samples were constructed in a similar size for each individual test to facilitate consistent measurements and comparable data. Three different wall assembly types were prepared as samples for testing, including:

1. Plaster on Wood Lath (traditional/historic assembly): Wall system made up of a 6”x6” sill of rough sawn Southern Yellow Pine, full size 2”x4” studs of Southern Yellow Pine spaced 16” on center, and a top plate of the same. Wood lath, 3/8” x 2” made of Southern Yellow Pine was installed with 8p wire nails fastened to the 2” x 4” studs. A standard 3/8” gap was included between the lath to allow the plaster to “key” to it. “Structo-Lite® Basecoat Plaster” was applied to the lath, and a scratch coat of lime plaster and washed masonry sand at a mixture of 5:1 was applied over the base coat. A final coat of pure slaked lime plaster, approximately 1/8” thick, was applied and troweled to a clean smooth finish. No hair or fiber was added to the base coat or scratch coat. The exterior of the wall assembly was covered with taper sawn Southern Yellow Pine, ½” thick, and nailed directly on the studs with galvanized 8p nails. Finally, a coat of Sherwin Williams oil-based exterior primer and a finish coat of exterior Latex paint was applied over the siding. The siding was not back primed on the interior. An interior oil-based primer was applied to the plaster, and Latex interior paint was applied as a finish coat. The plaster was allowed to cure for two weeks, and the finished paint was allowed to cure and dry for 72 hours.

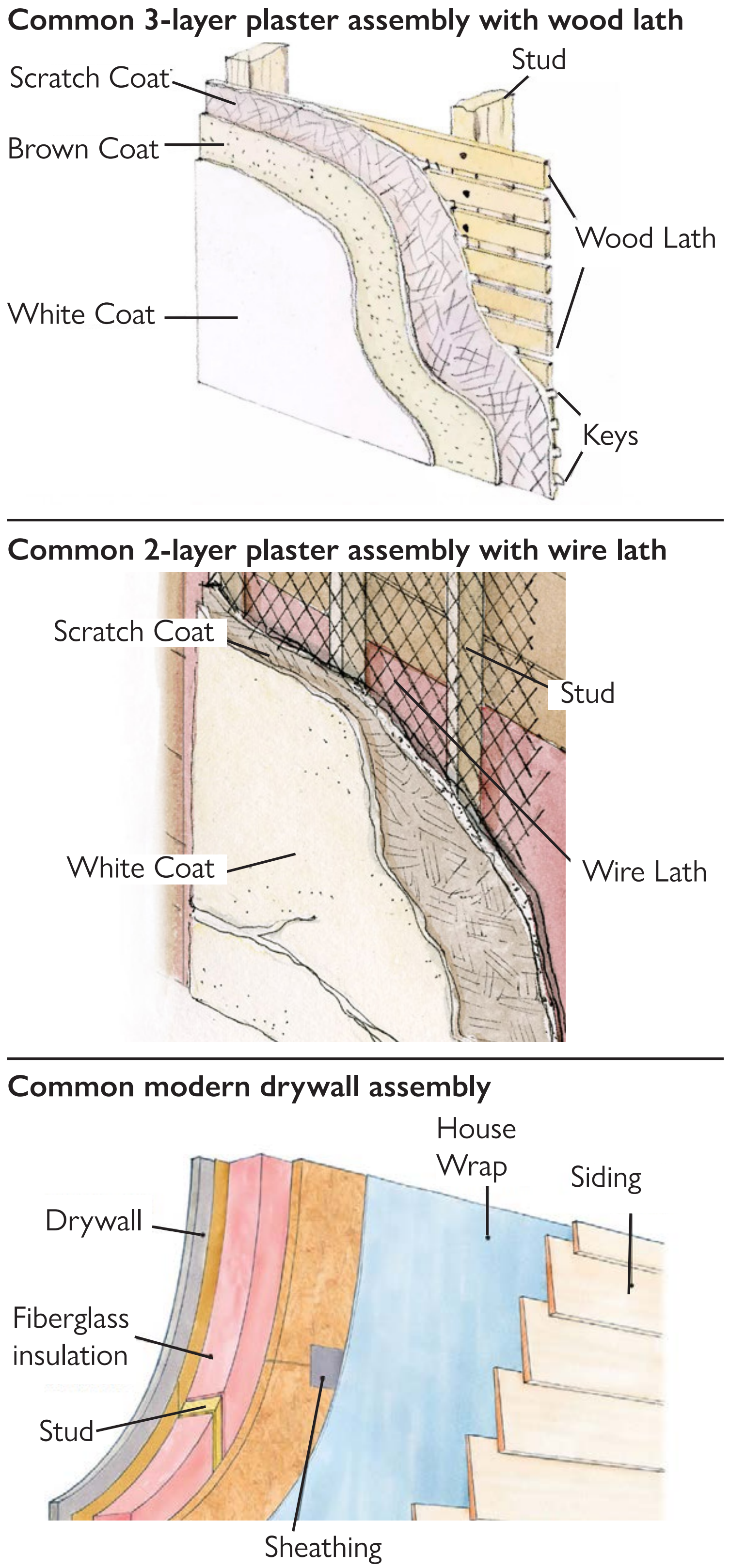


Figure 1 - Illustrations demonstrating the common materials and construction of the three types of wall assemblies built for this testing.

2. Plaster on Wire Lath (traditional/historic assembly): Wall system made up of a 6”x6” sill of rough sawn Southern Yellow Pine, full size 2”x4” studs of Southern Yellow Pine spaced 16” on center, and a top plate of the same. Standard expanded galvanized wire lath, fastened to the 2”x 4” studs with galvanized #8 x 1 1/2” lath screws. “Structo-Lite® Basecoat Plaster” was applied to the lath, and a scratch coat of lime plaster and washed masonry sand at a mixture of 5:1 was applied over the base coat. A final coat of pure slaked lime plaster, approximately 1/8” thick, was applied and troweled to a clean smooth finish. No hair or fiber was added to the base coat or scratch coat. The exterior of the wall assembly was covered with taper sawn Southern Yellow Pine, ½” thick, and nailed directly on the studs with galvanized 8p wire nails. Finally, a coat of Sherwin

Figure 2 - Sample 1 wall assembly of Plaster on Wood Lath (from top to bottom): “interior” plaster wall, assembly section, “exterior” siding

Williams oil based exterior primer and a finish coat of Sherwin Williams “Emerald” exterior Latex paint were applied over the siding. The siding was not back primed or painted on the inside surface. An interior oil-based primer was applied to the plaster and Latex interior paint was applied as a finish coat. The plaster was allowed to cure for two weeks, in unconditioned space, and the finished paint was allowed to cure and dry for 72 hours.

3. Modern Drywall (modern assembly): Wall system made up of a double sill of nominal size 2”x4” Southern Yellow Pine, nominal size 2” x 4” Southern Yellow Pine studs spaced 16” on center, and a top plate of single nominal size 2” x 4” Southern Yellow Pine. The cavity between the studs was filled with standard Owens Corning R-13 faced fiberglass insulation. The exterior of the studs was then covered with 7/16” Oriented Strand Board (OSB) fastened with 8p wire nails. The OSB was covered with “Tyvek®” house wrap and taper sawn Southern Yellow Pine, ½” thick, and nailed directly on the studs with galvanized 8p nails. The interior side of the assembly was covered with ½” Gold Bond High Strength Lite drywall and fastened with 1 ¼” steel drywall screws. The screws were recessed without breaking the paper covering and covered with one coat of lightweight drywall compound. Finally, a coat of Sherwin Williams oil-based exterior primer

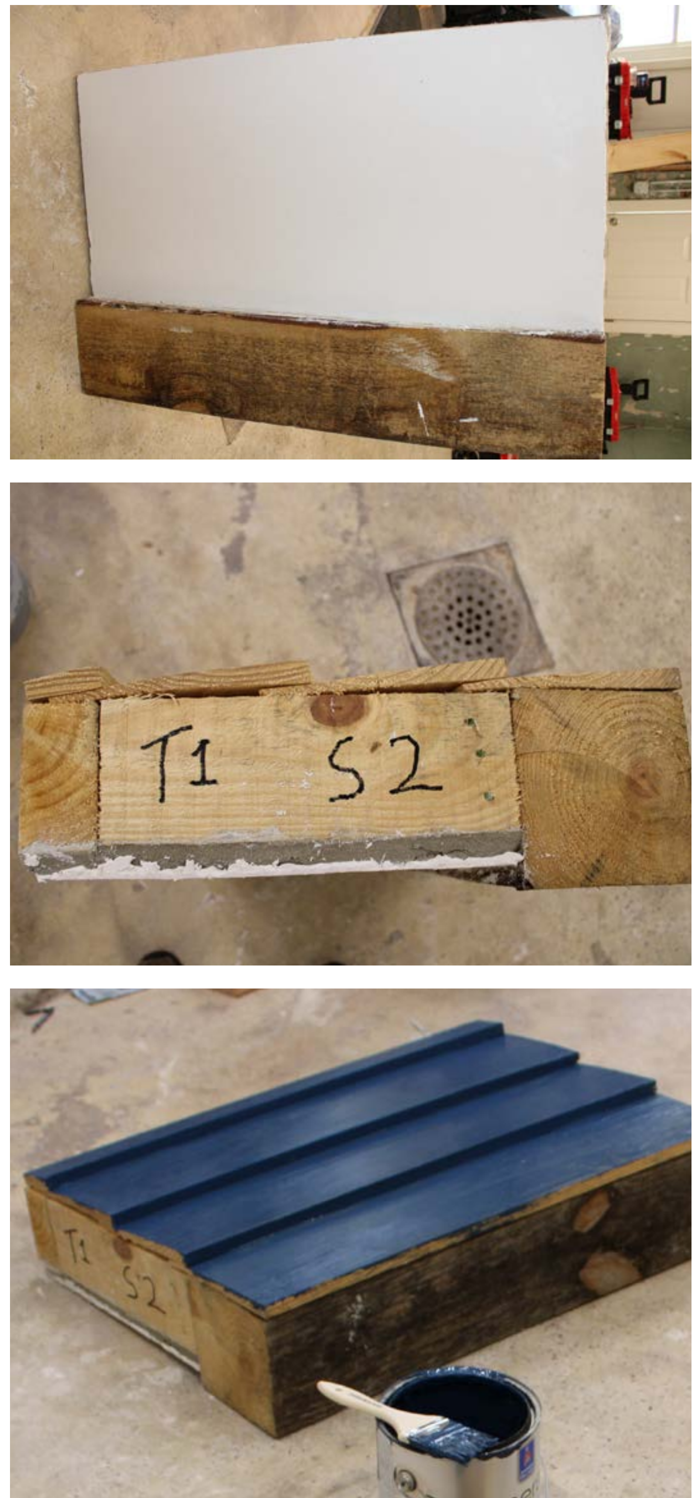


Figure 3 - Sample 2 wall assembly of Plaster on Wire Lath (from top to bottom): “interior” plaster wall, assembly section, “exterior” siding

Figure 4 - Sample 3 wall assembly of Modern Drywall (from top to bottom): “interior” drywall, assembly section, “exterior” siding

and a finish coat of Sherwin Williams “Emerald” exterior Latex paint was applied over the siding. The siding was not back primed or painted on the interior. A coat of Sherwin Williams interior oil-based primer was applied to the drywall and Sherwin Williams “Emerald” Latex interior paint was applied as a finish coat. The drywall compound was allowed to cure for two weeks, and the finished paint was allowed to cure and dry for 72 hours.

2.2 TEST CHAMBER

The chamber is insulated with 4” of polystyrene rigid insulation, and the tub is built of CMU coated in vinyl water proofing material designed to allow the porous masonry to maintain an even water level. The overall size of the chamber is 7’8” wide by 8’8” tall and 16’ long. The tub is 6’ wide by 2’8” deep and 2’8” wide. The test chamber was designed to allow for controlled flooding and drying by providing a controllable environment and consistent depth of water over the samples.

Chamber temperature, humidity, and water levels were all established and maintained within set values. Environmental conditions were monitored through use of remote sensors and recorded through a data logging system. Temperature was maintained using a small 1500-watt electric heater and a fan coil provided with chilled water via a water tank and pump. The water tank and pump

Figure 5 - Test Chamber.

system were located on the exterior of the chamber. The fan coil unit provided circulation of air to prevent stagnant temperature and Relative Humidity (RH). The fan, chiller, heater, and circulation pump were controlled by thermostatic probes set to specific high and low measurements that allowed for no more than five degrees of deviation. RH was controlled using both a humidifier and dehumidifier at the same setting to maintain consistent humidity levels.

The water used for flooding the samples was municipal tap water supplied by a spigot located directly over the tub. Water depth was measured with a simple ruler affixed to the sidewall of the tub. Water temperature was not controlled, but it was monitored and was the only environmental variable in the chamber.

Each test was monitored with a Lignomat data collection system that sent data to a local laptop computer for recordation; information was stored in the computer and in the BRS Dropbox file system for staff use. Data was collected using probes inserted into test material. The probes collected RH and moisture content levels for each sample.

The entire chamber and environs were also monitored by CCTV so that conditions and progress could be monitored off-site.

2.3 TESTING METHODOLOGY

The three wall assembly samples were tested together to ensure that environmental conditions and test parameters were consistent. Prior to running each test, all environmental systems in the test chamber were activated; systems were set to an approximate stable temperature of 70 degrees Fahrenheit and 70% RH. Prior to starting each test run, sample assemblies were allowed to rest inside the laboratory for three days to reach equilibrium with the current conditions inside the laboratory. Each sample was

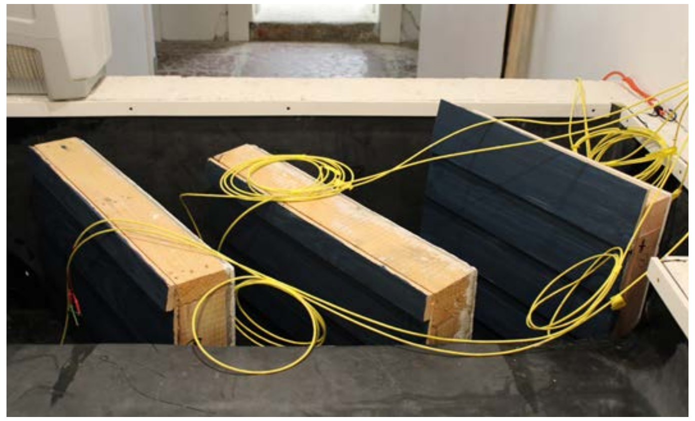


Figure 6 - Test chamber with assemblies pre-flooding.

assigned a sample number and photographed to record visual characteristics prior to testing. In preparation for each test, data from each sample was recorded on an individual Test Specimen Record Sheet (see Appendices). The data points collected included the assigned number for each specimen and physical attributes of each sample. Dimensional measurements were recorded in inches. Overall width, length, and height were recorded for each sample. Thickness of the overall wall and siding at specific locations were also recorded. Moisture content was measured with a pin-less probe, accurate to +/- 3%, using 3 points of collection, varying in position on the sample. Locations are listed for the siding, framing, and plaster/drywall at the same location each time during the post draining and extended drying periods to assess the drying rates in the vertical wall assemblies.

Samples were assessed for geometric deformations -- changes to the shape or physical character of a sample -- such as cupping (when a board's edges are higher than its center), crowning (when a board's center is higher than its edges), buckling (when a board bends or becomes uneven), or other distortions. The distortions were judged against a standard machinist straight edge and any deviations from a flat and uniform sample were noted. Specific measurements of these deviations were not recorded; instead, visual observations were made, along with a photographic record of the samples. All of this data was recorded on the Test Specimen Record Sheet for data analysis.

To monitor the moisture content of each sample, two 0.187-inch holes were drilled in both the framing and the plaster/drywall. Additionally, Lignomat probes were inserted into the siding of Sample 3 to assess the impact of the presence of insulation behind the siding. The holes were 1 1/12" apart and 3/8" deep. These probes were located in the center of the plaster wall and 3" from the top of the outside wall stud.

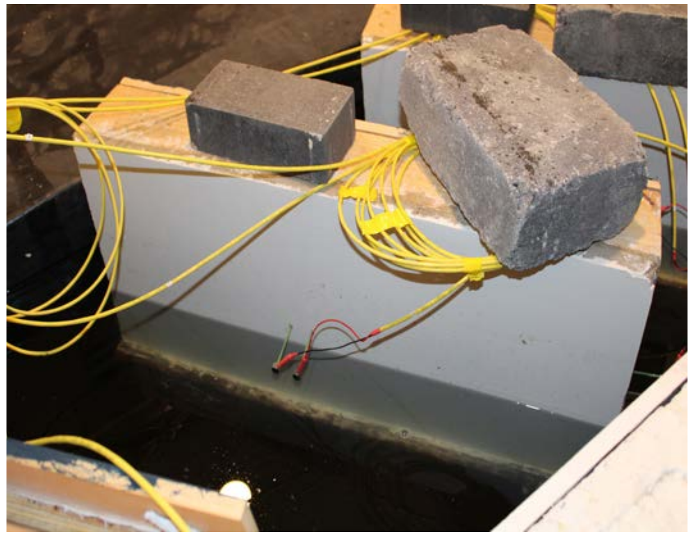


Figure 7 - Test chamber filled with water; flooding assemblies.

Figure 8 - Detail of measuring water level during flooding.

Testing was performed by placing each sample directly on the chamber floor. The appropriate leads for the moisture monitoring pins were then attached to the samples, and weights were placed across two stainless-steel angles situated on top of the sample material. This allowed for the minimum amount of surface contact while keeping the samples submerged.

Before testing was initiated, all recording systems were checked for operation. The Lignomat system was then activated and began recording measurements prior to flooding the tub. The tub was then flooded to a consistent level of 12", the date and time were recorded, and the chamber was sealed. At regular intervals the environmental conditions were checked and corrected if necessary to maintain conditions as close to the set points as possible.

Initially the test period was established as wetting for 72 hours and drying for seven days. When the wetting period was completed, the chamber was drained of water, time and conditions were recorded, and the initial 7-day drying period was started. The chamber was held at 70 degrees Fahrenheit and 70% RH during this initial drying phase. Moisture in the samples and temperature in the chamber were continuously monitored through the Lignomat system. When the initial drying phase was complete, data points were collected from the same locations as the pre-testing data

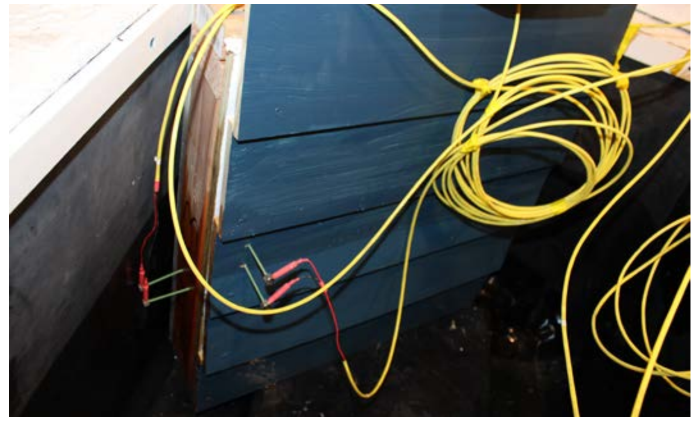


Figure 9 - Sample 1 assembly during draining

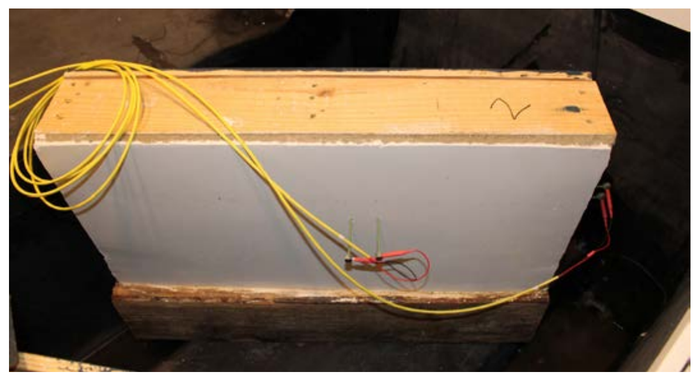


Figure 10 - Sample 2 assembly after draining

collection for each sample and recorded on the Test Specimen Record Sheet.

After the initial 7-day drying period, the samples had not yet returned to their pre-testing moisture levels. To allow the samples to dry completely, the drying period was extended to add an additional 14 days of drying, for a total of 21 days, and the chamber environment was adjusted to an elevated temperature of 80 degrees Fahrenheit and 70% RH. When this extended drying phase was complete, the same data points were once again collected for each sample and recorded on the Test Specimen Record Sheet.

2.4 DATA COLLECTION METHODS

- Length was measured using a flat machinist ruler to the nearest 0.031(1/32) inch.
- Thickness and width were measured in two locations using digital calipers to the nearest 0.001 inch.
- Moisture content was monitored throughout the duration of testing using Lignomat Probes installed into each sample at multiple points. These probes measure moisture content to the nearest 0.1 percent.
- Moisture content was measured during designated data collection periods using a pin-less Wagner moisture meter to the nearest 0.1 percent.
- Flatness was checked using a machinist straight edge held across the surface.

Figure 11 - Measuring moisture content after draining.

3. TEST RESULTS

3.1 SAMPLE 1 - PLASTER & WOOD LATH

The Sample 1 wall assembly was constructed of Southern Yellow Pine framing, wood lath, lime plaster, and taper sawn Southern Yellow Pine siding, as described above in Test Methods: Materials for Testing. Prior to testing, the data was collected from several locations on the sample. Overall, Sample 1 measured 30" long, 20.24" tall, and 6" thick. The siding was measured at the thickest point where two layers overlap and was 1" thick. Total wall thickness was made up of 4" of wood, 1" of siding, and 1" of plaster and lath. Moisture content levels recorded in the framing averaged 14.2%, the siding averaged 6.8%, and the plaster averaged 19.8%. Moisture readings for the framing and siding were taken at the bottom and top of the wall assembly to later compare the movement of moisture up the wall during the flooding event. The right side of the upper plate had an average moisture content of 17.4%, which was slightly higher than the 12% average in the remainder of the framing. The plaster and siding both had relatively consistent average moisture contents at the top and bottom of the wall column. The plaster wall was flat and smooth, containing no rough areas. The siding was smooth and did not contain rough areas or show any areas of cupping or deviations from a flat surface.

After the 72-hour wetting period, the tank was drained, and all data points were immediately recorded as described below. Moisture content levels from the framing's top plate

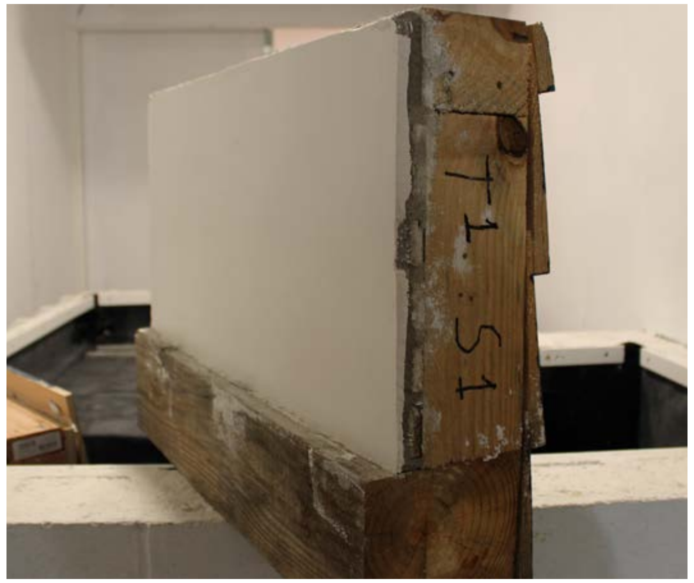


Figure 12 - Sample 1 assembly prior to flooding.

were recorded as being lower after the flood event than they were prior to testing, averaging 13.4% post-flooding compared to 17.4% pre-flooding. While this seems to be an anomaly, this change may have been caused by the top plate containing more moisture initially and the capillary movement of water not reaching the top plate during flooding, resulting in the wood drying out in the chamber's 70% RH and 70-degree environment. Comparatively, measurements taken in the vertical members of the framing 3" below the top plate had an average moisture content of 32% or higher (the sensitivity limit of the meter does not go higher than 32%). This measurement indicates that water moved up the vertical members of the wood framing to within at least 3" of the top plate. The siding and plaster both measured a moisture content of 32% at the top and bottom of the column.

After the wetting period, the siding had expanded from 1.10 inches in width to 1.15 inches; two sections were cupped across the width of the siding, and one section split due to the swelling against the fasteners that held the siding to the framing. The plaster and lath both appeared to be in good condition and no surface deformations were visible. The plaster did develop a sandy, crystal-like substance above the waterline. The wood lath was intact; fasteners were holding well against the plaster and no cracking was visible between the framing and the plaster. The framing members, while laden with moisture, did not change in size in any measurable form. This may be a result of the larger sections of wood and heavy sill used in the framing, which tend to show less overall movement in cross-sectional dimensions than smaller sections of wood.

A drying period of seven days began after the tank was drained, and the chamber was held at 70 degrees and 70% RH. During this time, the moisture content within the wall assembly decreased, and the framing returned close to the pre-test moisture content levels. After the 7-day drying period, the top plate had decreased to 13% moisture content and the studs averaged 12.7%. When measured in specific locations, the studs had an average moisture content of 14.9% at the bottom and 11.5% at the top. The siding's moisture content remained high at an average of 28.5% with little variation from top to bottom. The plaster also retained a high 32% moisture content, perhaps contributing to the moisture levels in the siding. Although the siding was located 4" away from the wet plaster, the cavity between them likely carried a high volume of water vapor that could be absorbed into the siding. The framing, again being larger in cross section, did not appear to absorb as much moisture from the wet plaster. The plaster continued to produce efflorescence (crystals) on the surface, which could be brushed off and did not harm the surface material. The plaster surface otherwise remained flat and smooth. Cupping in the siding continued to increase and all five pieces of siding exhibited some form of cupping. The thickness of the siding decreased from 1.10-1.15 to 1.03, bringing it close to the pre-testing measurement of 1.0 inches. No significant changes were noted in the cross-sectional dimensions of the framing material.

Since the wall assembly had not dried to the pre-testing moisture levels, the drying period

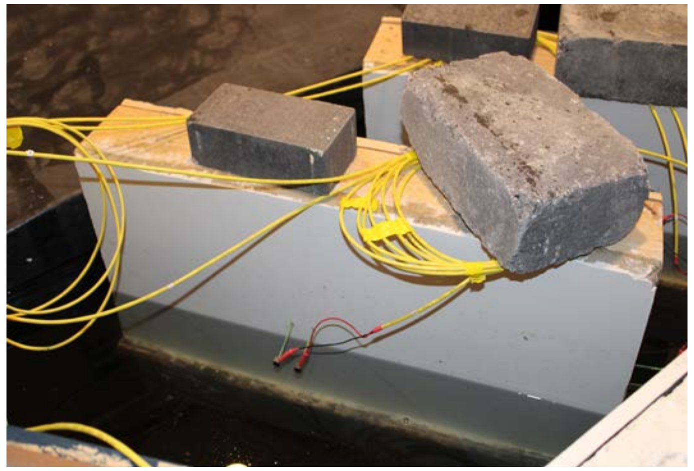


Figure 13 - Sample 1 assembly during flooding.

TABLE 1 - Sample 1 Average Thickness Measurements (inches)		
	Wall	**Siding**
Pre-Testing	6.00	1.00
Post-Draining	6.13	1.13
First Drying Period	6.05	1.03
Second Drying Period	6.02	1.00

was extended for 14 days. In an attempt to bring the conditioned air to an optimum range for mold growth, the environment within the chamber was adjusted to a temperature of 80 degrees Fahrenheit and 70% RH. Moisture content, thickness measurements, and deformation data was collected after the additional drying period concluded. The top plate had dried to an average of 8.5% in the warmer environment of the chamber. The vertical members (studs) also dried to an average of 11%, with the bottom containing on average of only 13.5%. The plaster measured at an average of 11.5% moisture content. The siding had decreased to 12.5% moisture content and had returned to its pre-testing thickness of 1.0". The plaster continued to show efflorescence (crystals) on the surface; however, the surface was flat and smooth once the crystals were brushed off. There were no signs of mold, mildew, or discoloration on the siding or plaster. The lath remained fastened to the framing and exhibited little to no separation from the plaster. The framing remained true, straight, and had little to no change in cross sectional dimensions. The siding remained cupped. The split that had previously developed in one piece of siding separated to a dimension of 0.25" at the leading edge; this split was located in the center of the broad face and appeared to be a result of cupping and swelling that placed stress on the board since it was nailed in place and unable to move or grow across the grain. The sample was photographed to record its appearance (See Figure 14).

Figures 14 - Sample 1 showing cupped siding against a flat edge.

Figures 15 - Sample 1 after final drying.

3.2 SAMPLE 2 - PLASTER & WIRE LATH

The Sample 2 wall assembly was constructed of Southern Yellow Pine framing, galvanized wire lath, lime plaster, and taper sawn Southern Yellow Pine siding, as described above in Test Methods: Materials for Testing. Prior to testing, the data was collected from several locations on the sample. Overall, Sample 2 measured 30" long, 20.5" tall, and 6" thick. At the thickest point where two layers overlap, the siding measured 1.0" think; this is the dimension that was recorded consistently. Total wall thickness was made up of 4" of wood, 1" of siding, and 1" of plaster and lath. Moisture levels within the framing averaged 10.5%, the siding averaged 10.2%, and the plaster averaged 17.5%. Readings for the framing and siding were taken at the bottom and top of the wall assembly to later compare moisture movement within the wall column during the flooding event. The moisture content in the bottom of the siding where it was nailed over the heavy sill was 6.5%; this measurement was less than the other portions of the siding assembly which averaged 10.1%. The moisture content in both the plaster and siding was relatively consistent in the top and bottom of the wall column. The plaster was flat, smooth, and did not contain rough areas. The siding was smooth and did not contain rough areas or show any areas of cupping or deviations from a flat surface.

After the 72-hour wetting period the tank was drained, and all data points were immediately recorded. The framing's top plate had increased

Figure 16 - Sample 2 construction showing plaster.

slightly from the pre-testing moisture content of 10.2% to 12.4%. The vertical members (studs), however, contained an average of 32.3% moisture content with little variation from top to bottom. The plaster moisture levels had a consistent moisture content of 32% from top to bottom. The siding varied only slightly from top to bottom with an average moisture content of 31%. The siding swelled to an average thickness of 1.18" and the framing expanded 0.08" for a total thickness of 6.09". The siding was cupped across the broad surface of the plank, but no visible checks or cracks were found. The plaster was smooth, flat, and, like Sample 1, covered with efflorescence (crystals) near the level of water during the flooding. The wire lath remained intact; the fasteners were still in place and holding well, and it was not separated from the framing along the exterior edges. The cut ends of the wire lath did produce some rust staining, but it was not significant. The sample was photographed from all angles to record its appearance.

TABLE 2 - Sample 2 Average Thickness Measurements (inches)

	Wall	Siding
Pre-Testing	6.00	1.00
Post-Draining	6.09	1.18
First Drying Period	6.06	1.06
Second Drying Period	6.00	1.06

The data collected after the 7-day drying period did not show significant moisture loss in the wall assembly, as quantified below. The top framing increased to an average moisture content of 12.4%, while the vertical members (studs) remained at 31.5% from top to bottom. The siding retained a high moisture content of 23.7% with little change from top to bottom. Moisture levels in the plaster remained at 32% from top to bottom. The siding shrank in cross section from 1.18" to 1.06". Framing materials decreased in thickness from 6.08" to 6.06" in total. After the 7-day drying period, the plaster was flat, smooth, and in good condition but remained covered with crystals. The lath retained good contact with the plaster; the fasteners were holding and no cracks were noted between the framing and plaster. Cupping in the siding remained much as it was after draining with no noticeable checks or cracking.

The Sample 2 assembly was allowed to continue drying for the additional 14-day period. The moisture content of the top plate dropped to an average of 10.5%, and the vertical members (studs) were now an average of 11.2% with a slight variation in moisture from top to bottom (8.7% - 13.5%). Moisture in the plaster was consistent at an average of 12.3%, and the siding averaged 8.8% with little difference from top to bottom. The framing dimensions returned to the pre-test measurements of 6" thick. The siding, however, remained swollen at 1.06" compared to its pre-wetting measurement of 1.00" thick. No noticeable changes in the cupping or additional checks or cracks were found in the siding. The plaster remained flat and smooth. Crystals remained, except where previously brushed off, and no appearance of new crystals were found. There were no signs of mold, mildew, or discoloration on the siding or plaster. The lath remained in place and was holding the plaster, and the fasteners were still holding to the framing.

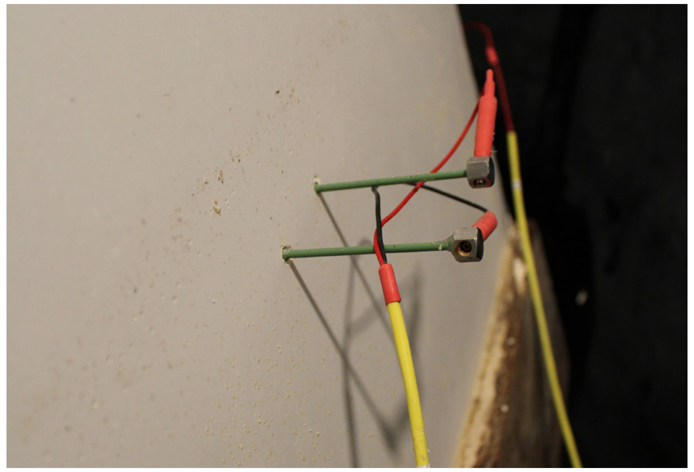


Figure 17 - Detail of Sample 2 assembly showing crystal granules formed on drywall after flooding

3.3 SAMPLE 3 - DRYWALL

The Sample 3 wall assembly was constructed of Southern Yellow Pine framing, R-13 faced fiberglass insulation, Oriented Strand Board (OSB), Tyvek house wrap, drywall, and taper sawn Southern Yellow Pine siding, as described in Section 2.1(3). Prior to testing, the data was collected from several locations on the sample. Overall, Sample 3 measured 24" long, 24" tall, and 5.94" thick. The siding was measured at the thickest point where two layers overlap and was 1" thick. The total wall thickness was made up of 0.50" of drywall, 3.50" of solid wood, 0.43" of OSB, a layer of Tyvek house wrap, and siding for a total thickness of 5.94". The framing's moisture levels averaged 9.4%, the siding averaged 9.9%, and the drywall averaged 9.7%. Readings for the framing and siding were taken at the top and bottom of the wall assembly to later compare the movement of moisture in the wall column during the flooding event. The drywall, framing, and siding all had relatively consistent moisture levels from the top of the wall column to the bottom. The drywall was flat, smooth, and did not contain rough areas. The siding was smooth and did not contain rough areas or show any areas of cupping or deviations from a flat surface.

After the 72-hour wetting period the tank was drained, and all data points were immediately recorded as described below. The moisture content in the framing's top plate increased to 13.9%, and the vertical members (studs) averaged 21.6% with the top averaging 22.7%

Figure 18 - Sample 3 assembly ready for test chamber

and the bottom averaging 32%. The drywall contained a uniform moisture content of 32%. The siding averaged 22.4%, with the top averaging 12% and the bottom averaging 32%. The overall wall thickness swelled form 5.85" to an average of 5.99" and the siding expanded from 1.02" to an average of 1.07". The drywall was rough to the touch, easily scratched, and the paper had separated from the gypsum on the edges. Physical changes in the siding were the most visible change in the sample. The siding showed significant cupping and some cracking around the nails.

TABLE 3 - Sample 3 Average Thickness Measurements (inches)		
	Wall	**Siding**
Pre-Testing	5.85	1.02
Post-Draining	5.99	1.07
First Drying Period	6.00	1.00
Second Drying Period	5.94	0.94

At the end of the 7-day drying period moisture data was again collected from the drywall, framing, and siding, as were measurements of the wall framing and siding thicknesses. Moisture levels in the framing's top plate increased to an average of 16.9% while the vertical members (studs) averaged 16.7% with a range of 12.8% - 21% from top to bottom. The drywall remained consistent with 32% moisture content, and the moisture content in the siding was 21% at the end of the 7-day drying period. The overall wall thickness increased from 5.99" to 6.0" and the siding thickness returned to its pre-test 1.0" width. The drywall and siding were consistent in moisture levels from top to bottom. Geometric deformations in the siding increased during the initial drying period. Four sections of siding were severely cupped and cracking around the nails. The drywall still had a rough texture and the separations at the edges remained but did not increase in area or quantity.

Following the additional 14-day drying period, Sample 3 showed a return to near the pre-test moisture levels in the top plate at an average of 8.7%. The moisture content levels decreased, but did not fully return to their pre-test levels. The vertical members averaged 10.1%, the siding averaged 9.0%, and the drywall averaged 7.8%. Interestingly, the moisture content in the drywall measured lower than the pre-test levels, dropping from 9.7% to 7.8%. The overall wall thickness was 5.94" and the siding thickness decreased to 0.94". Geometric deformations in the siding continued to increase and many sections showed even greater cupping across the broad surfaces. The drywall, while rough in texture, dried to a flat surface, and no additional separation of the paper from the gypsum layer was observed. The screws in the drywall did develop some dimples around them, but the paper stayed intact. There were no signs of mold, mildew, or discoloration on the siding or the plaster.

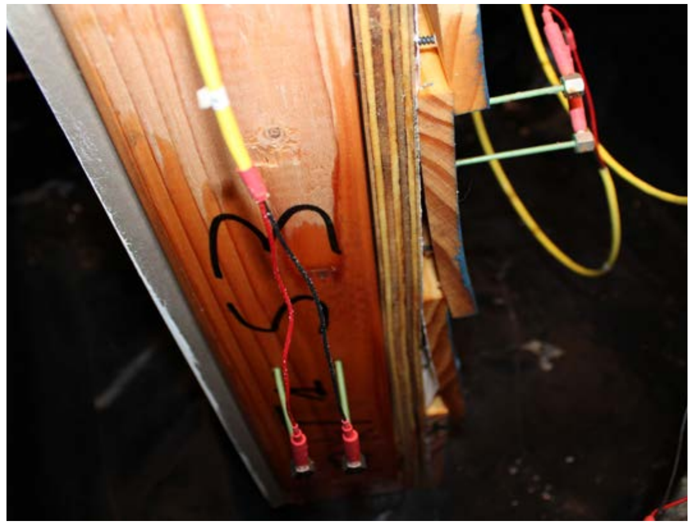


Figure 19 - Sample 3 assembly post-draining showing wet areas on sample and warped siding

4. CONCLUSIONS

Testing carried out in a controlled environment can never replicate the exact flooding conditions found in the natural environment. The purpose of the tests conducted in this investigation was to measure and compare the performance of the samples under controlled conditions that could be replicated on any number of other samples. This approach allowed for the examination of specific characteristics that would cause failure in a wall system, specifically in the plaster/drywall and the siding. Performance for these tests was judged by the gained or lost values of each of the recorded measurements and visual observations. Change in these values was used as a performance indicator for each of the listed materials; both negative and positive change equally have the potential to affect performance.

The swelling and contraction of the wood fibers affects the fasteners' ability to grip the substrate. This is true in the exterior and interior cladding. Siding was adversely affected by the gain in moisture which caused a gain in width and thickness, and in turn, placed strain on the fasteners and forced failure in the wood in most cases. Differential wetting and drying of the siding caused the fibers to expand on each side of the planks; the extent of the expansion varied. Expansion of fibers on the interior side of the planks caused the planks to cup. This cupping was enhanced when the exterior of the planks dried at a faster rate than the interior, increasing the differential drying between exterior and interior. Samples 1 and 2 were built with the siding placed directly on the studs, with no exterior sheathing or weather-resistive barrier (WRB). Sample 3 not only included sheathing and a WRB, but the cavities were also filled with Owens Corning R-13 faced fiberglass insulation. The addition of these materials caused the Sample 3 assembly to maintain a higher moisture level behind the siding, which in turn contributed to the greater geometric deformation of the siding in Sample 3. Geometric changes in the siding may have also been influenced by the siding only being painted on the exterior. This would allow the absorption and evaporation rates to be considerably different on the two sides of the siding material. While the addition of sheathing and weather barriers is necessary in modern buildings, they result in changes to the performance of the siding, including its drying ability. In Sample 3, the siding was painted only on one side and a water barrier was in place which allowed for differential drying. This differential drying in Sample 3 caused the siding to cup during the initial drying period and promoted continued cupping throughout the extended drying period. Comparatively, Samples 1 and 2, which did not include modern sheathing and weather barriers, did not continue to cup or deform during the extended drying period.

The overall performance of the interior finishes was better than anticipated. The plaster samples survived with little to no changes in measured values or deformations. The efflorescence (crystals) that formed on the plaster were easily removed with a soft brush and the surface was unchanged. No noticeable changes in the fasteners or the connections to the lath or substrate were observed in any of the samples. The drywall was the most surprising performer. The surface, while a little rough, had little to no change in the measured thickness of the wall framing and siding. The edges where water could easily penetrate the joint between the paper and gypsum performed poorly. This would be an issue in a wall assembly with many cut openings for electrical outlets, doors, windows, etc. The performance of the drywall, and perhaps the plaster, may have been influenced by the application of oil-based primer and high-quality latex paint that was in good condition. This may not be the case with many wall assemblies in the field as paint may have been abraded in areas on the wall which would allow more moisture to penetrate the paper/gypsum connection.

During the final extended drying period, an attempt was made to create an environment conducive to mold and mildew growth, because flood waters are often contaminated with a variety of organisms (such as spores) in sufficient quantities to produce mold and mildew growth on many of these surfaces. In the test, however, the effects of raising the temperature of the conditioned air in the test chamber may have actually had the reverse effect of drying the samples without establishing the correct parameters for fungal growth. The use of clean water that was likely treated by the municipality, however, may have lessened the impact and opportunity for the growth of these organisms.

Of the three samples tested, Sample 1 performed the best. This sample was composed of heavy framing, wood lath, and wood siding nailed directly to the framing. Surprisingly, the overall wall assembly expanded the least in cross section and, upon drying, returned to close to the original values. The difference in the overall performance between Samples 1 and 2 is minor and was within the margin of error for the tools used in collecting the data and sample size. Visual observations were similar in both samples as well. While the performance of Sample 3 inferior to the performance of Samples 1 and 2, it was still a survivable wall assembly for the test performed.

The overall effects of the method and rate of drying were inconclusive as evaluated in this testing protocol. Sample 3 continued to produce geometric deformations in the siding; these deformations may have been due to other factors like the use of WRB, sheathing, or the method and product used to paint the siding.

4.1 FURTHER TESTING

While the tests performed in this study have confirmed the survivability of historic materials, and, to a lesser extent, the modern materials, more testing is needed. Multiple samples of each type of wall assembly should be tested together to provide a better sample pool for analysis. Moisture levels within the samples should also be measured from additional locations, including the interior of the wall cavity. Historic wall assemblies are often insulated, have their exterior cladding changed, and have water-resistive barriers added. Testing should include modifications to historic wall assemblies and their effects on the performance of the overall assembly. In addition, the environment of the chamber should be altered to better simulate post-flood conditions that foster fungal growth, and the effects of elevating temperature and RH within the chamber should be examined. The geometric deformations in the siding should be examined with the addition of data collected from a group of samples including fastener type and location, grain orientation, and differential drying. The location of the fasteners, along with the type of fasteners could impact the survivability of the siding. Exploring the rate of moisture loss over time along with changes in environmental conditions in the chamber should be compared to the geometric changes in the siding and framing materials. Additional testing could also be used to evaluate the effects of mechanical ventilation introduced into wall cavities to facilitate accelerated drying. Finally, the addition of contaminated water to evaluate the impact environmental conditions have on fungal growth could also be beneficial for better risk assessment in the field.

APPENDICES

APPENDIX A: SAMPLE 1 - PLASTER & WOOD LATH

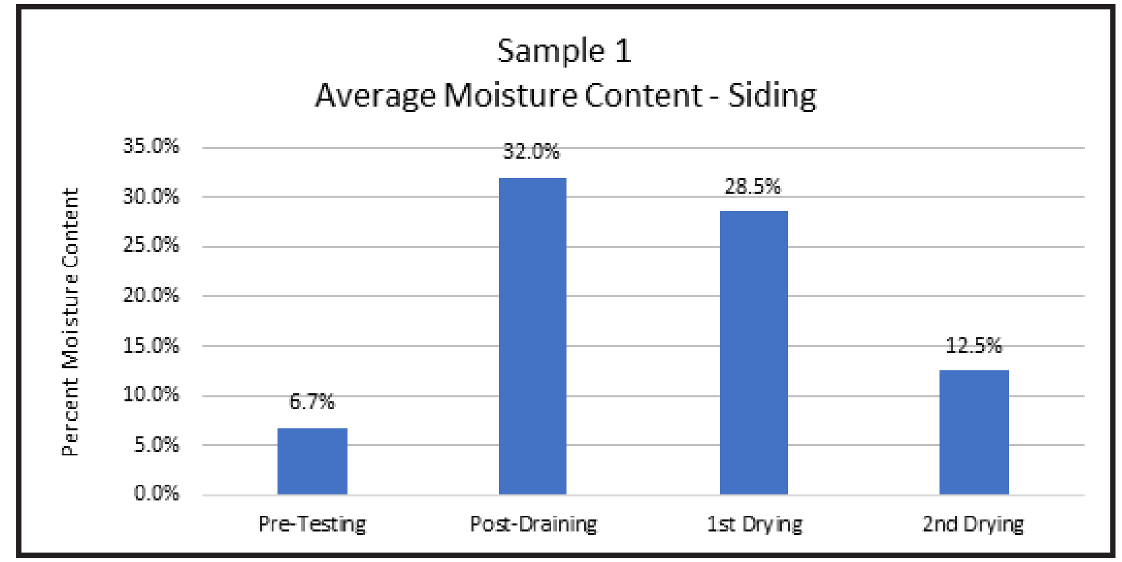
The following pages include the Testing Specimens Record Sheet for the Sample 1 specimen, Sample 1 Results Graphs, and Sample 1 photographs.

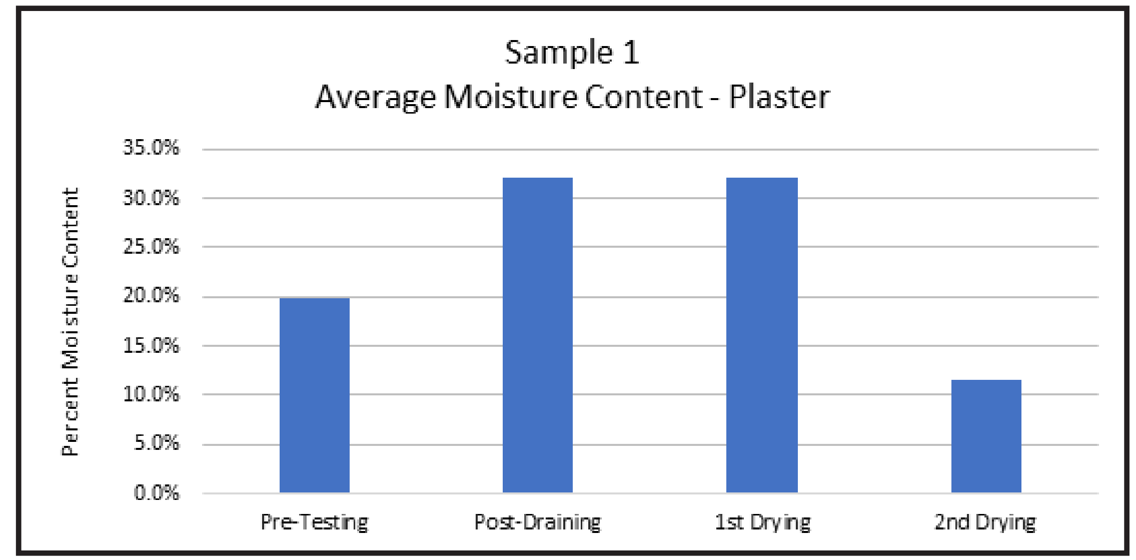
Appendix A1: Sample 1 Specimen Record Sheets

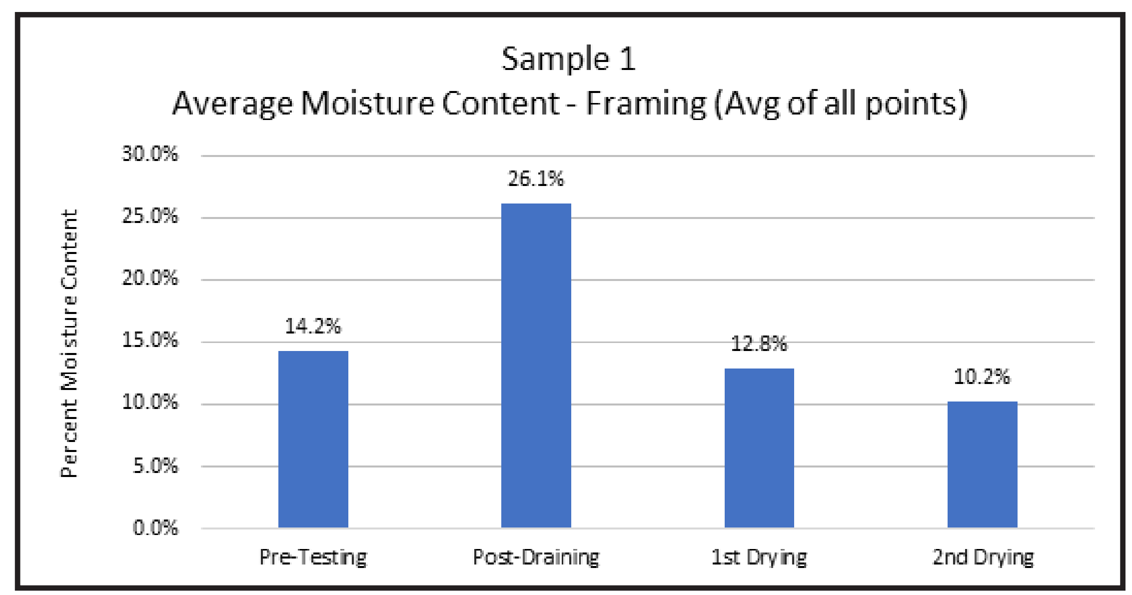
Test Sample Record Sheet					
Test Protocol #	2		Date	10/24/22-11/3/22	
Sample #	1	**Sample Name:**	Wall System - Plaster with Wood Lath		
Pre-Test Characteristics					**AVG**
Moisture Content					
Siding		**1**	**2**	**3**	
		6.5%	6.9%	6.7%	**6.7%**
Framing	**Top**	**Right End**	**Left End**		
		15.9%	18.9%		**17.4%**
	Right Side	**Top**	**Bottom**		
		12.3%	12.6%		**12.5%**
	Left Side	**Top**	**Bottom**		
		12.7%	12.8%		**12.8%**
Plaster		**1**	**2**	**3**	
		20.0%	19.5%	20.0%	**19.8%**
Thickness (inches)					
Siding		**1**	**2**		
		1.00	1.00		**1**
Wall		**1**	**2**		
		6.00	6.00		**6.00**
Post-Draining Test Characteristics					**AVG**
Moisture Content					
Siding		**1**	**2**		
		32.0%	32.0%		**32.0%**
Framing	**Top**	**Right End**	**Left End**		
		13.0%	13.8%		**13.4%**
	Right Side	**Top**	**Bottom**		
		32.3%	32.4%		**32.4%**
	Left Side	**Top**	**Bottom**		
		32.3%	32.4%		**32.4%**
Plaster		**1**	**2**		
		32.0%	32.0%		**32.0%**
Thickness (inches)					
Siding		**1**	**2**		
		1.15	1.10		**1.13**
Wall		**1**	**2**		
		6.15	6.11		**6.13**

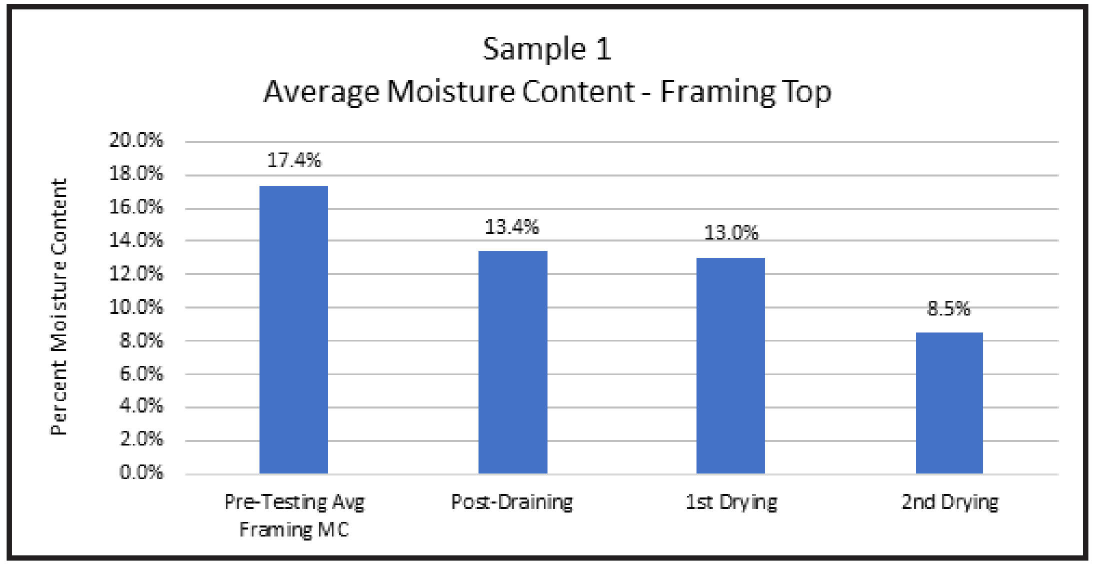
Test Sample Record Sheet, Continued					
Test Protocol #	2		Date	10/24/22-11/3/22	
Sample #	1	**Sample Name:**	Wall System - Plaster with Wood Lath		
Post-First Drying Period Characteristics					**AVG**
Moisture Content					
Siding		**1**	**2**		
		29.0%	28.0%		**28.5%**
Framing	**Top**	**Right End**	**Left End**		
		13.7%	12.2%		**13.0%**
	Right Side	**Top**	**Bottom**		
		13.0%	14.8%		**13.9%**
	Left Side	**Top**	**Bottom**		
		10.0%	13.0%		**11.5%**
Plaster		**1**	**2**		
		32.0%	32.0%		**32.0%**
Thickness (inches)					
Siding		**1**	**2**		
		1.05	1.00		**1.03**
Wall		**1**	**2**		
		6.07	6.03		**6.05**
Post-Second Drying Period Characteristics					**AVG**
Moisture Content					
Siding		**1**	**2**		
		12.0%	13.0%		**12.5%**
Framing	**Top**	**Right End**	**Left End**		
		8.0%	9.0%		**8.5%**
	Right Side	**Top**	**Bottom**		
		8.0%	13.0%		**10.5%**
	Left Side	**Top**	**Bottom**		
		9.0%	14.0%		**11.5%**
Plaster		**1**	**2**		
		12.0%	11.0%		**11.5%**
Thickness (inches)					
Siding		**1**	**2**		
		1.00	1.00		**1.13**
Wall		**1**	**2**		
		6.15	6.11		**6.13**

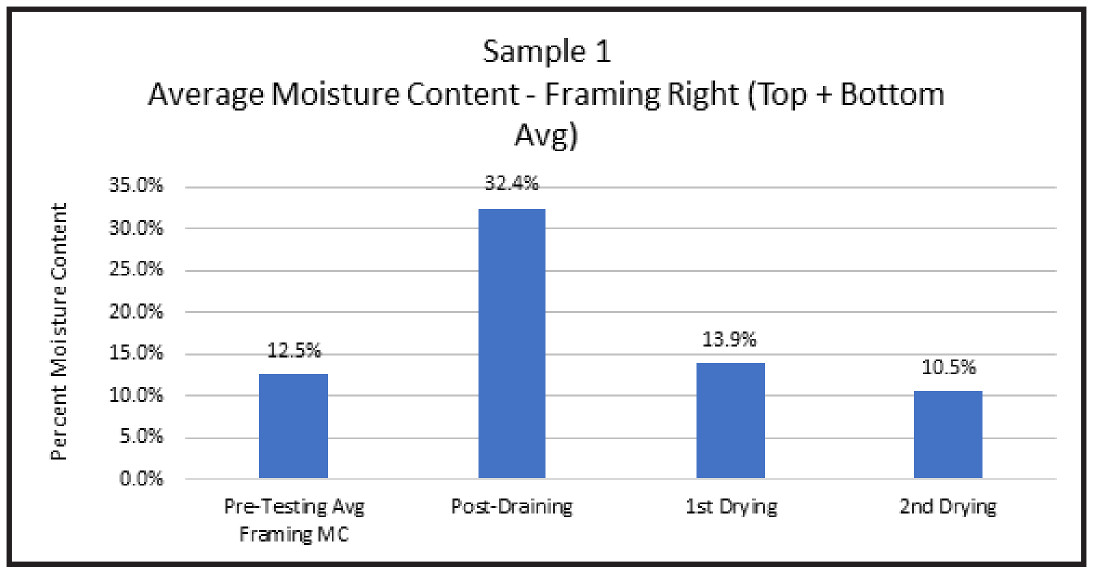
Appendix A2: Sample 1 Results Graphs

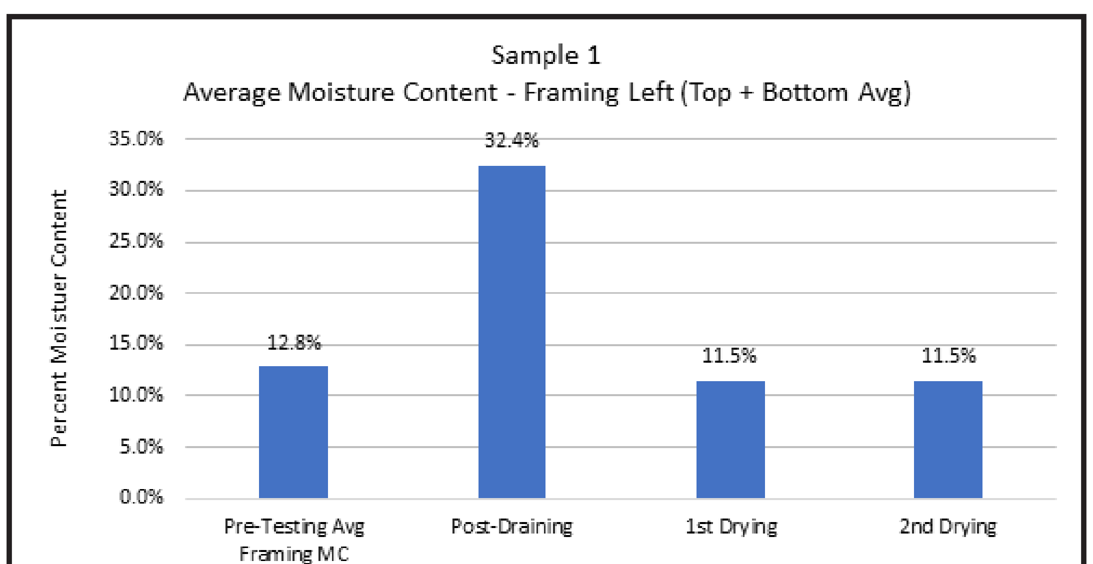


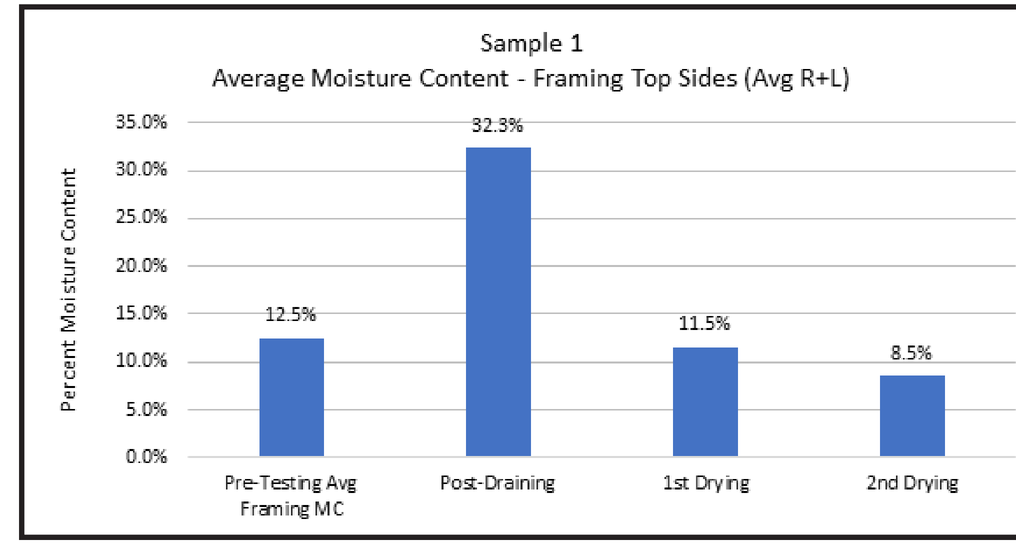


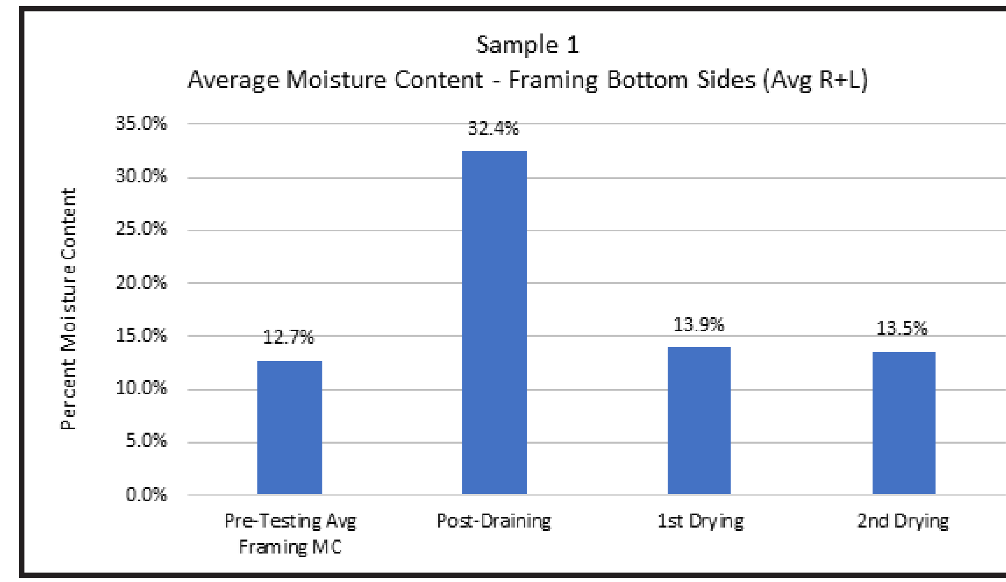


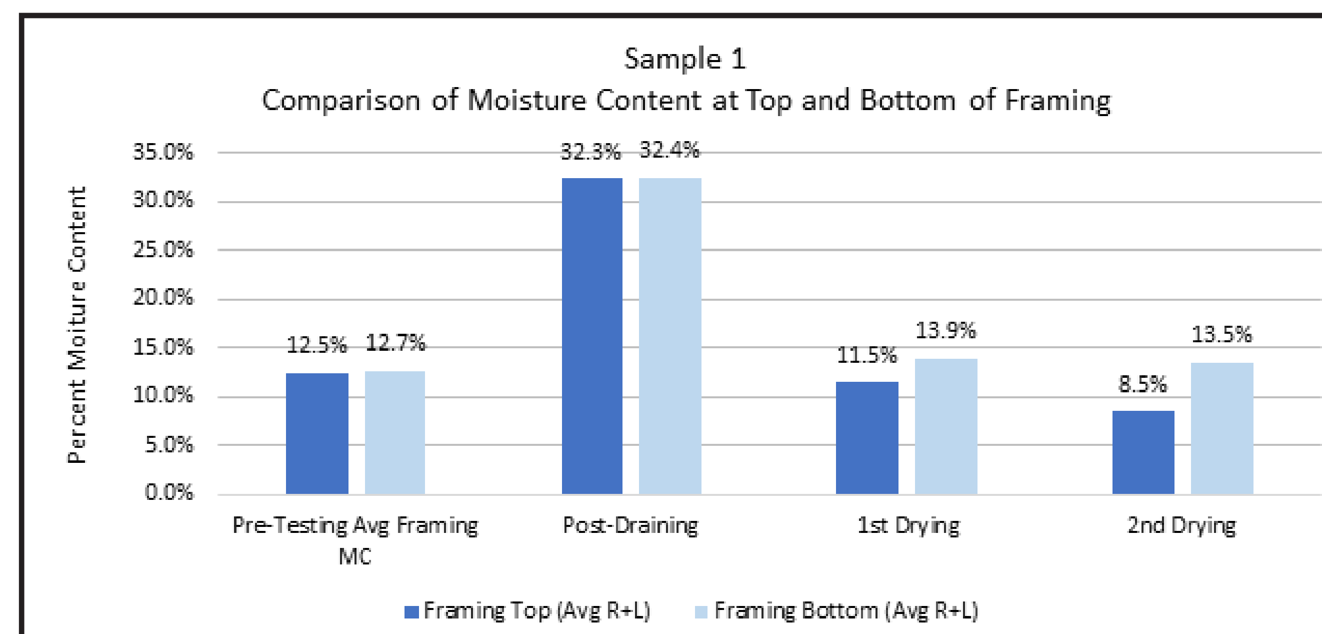

Sample 1
Average Moisture Content - Framing Top
Percent Moisture Content
20.0%
18.0%
16.0%
14.0%
12.0%
10.0%
8.0%
6.0%
4.0%
2.0%
0.0%
17.4%
13.4%
13.0%
8.5%
Pre-Testing Avg Framing MC
Post-Draining
1st Drying
2nd Drying

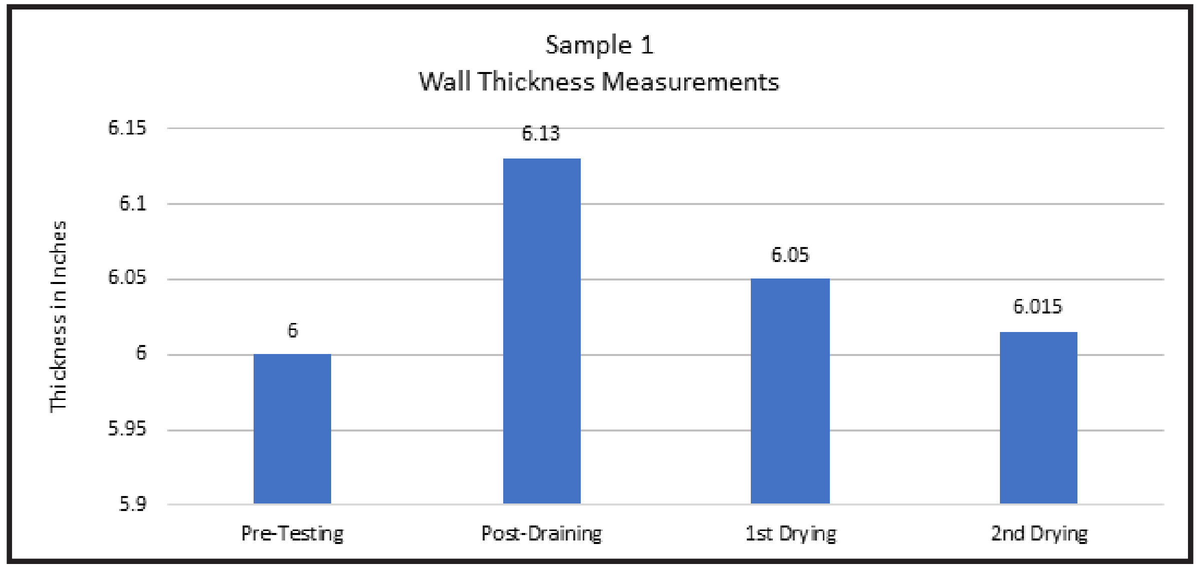

Sample 1
Average Moisture Content - Framing Right (Top + Bottom Avg)
Percent Moisture Content
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
12.5%
32.4%
13.9%
10.5%
Pre-Testing Avg Framing MC
Post-Draining
1st Drying
2nd Drying

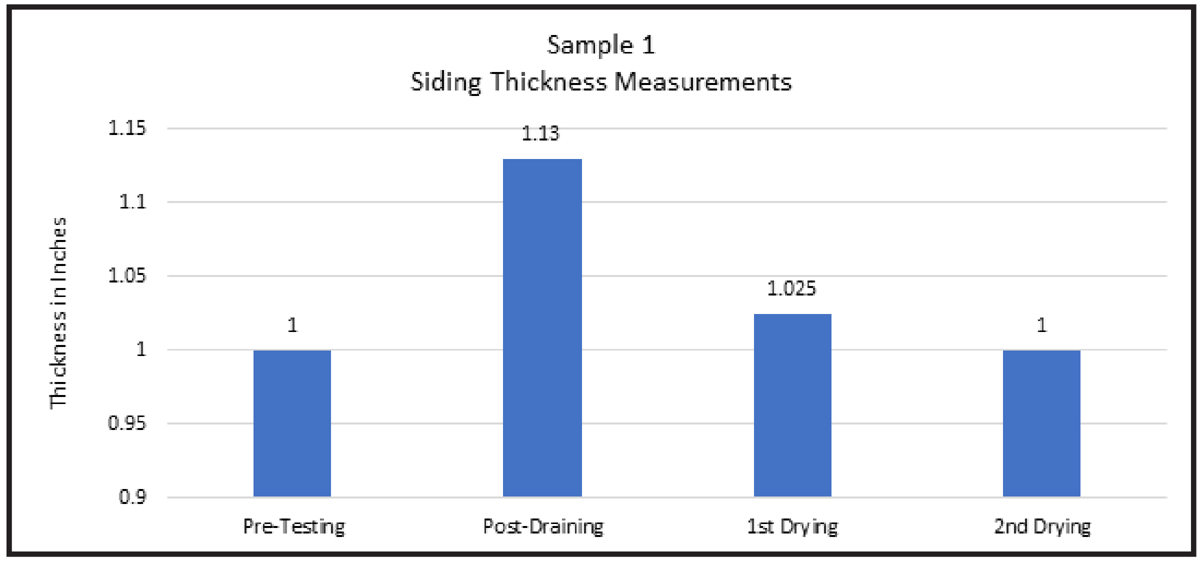

Sample 1
Average Moisture Content - Framing Left (Top + Bottom Avg)
Percent Moistuer Content
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
12.8%
32.4%
11.5%
11.5%
Pre-Testing Avg Framing MC
Post-Draining
1st Drying
2nd Drying


Sample 1
Average Moisture Content - Framing Top Sides (Avg R+L)
Percent Moisture Content
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
12.5%
32.3%
11.5%
8.5%
Pre-Testing Avg Framing MC
Post-Draining
1st Drying
2nd Drying


Sample 1
Average Moisture Content - Framing Bottom Sides (Avg R+L)
Percent Moisture Content
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
12.7%
32.4%
13.9%
13.5%
Pre-Testing Avg Framing MC
Post-Draining
1st Drying
2nd Drying


Sample 1
Comparison of Moisture Content at Top and Bottom of Framing
Percent Moiture Content
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
12.5%
12.7%
32.3%
32.4%
11.5%
13.9%
8.5%
13.5%
Pre-Testing Avg Framing MC
Post-Draining
1st Drying
2nd Drying
Framing Top (Avg R+L)
Framing Bottom (Avg R+L)





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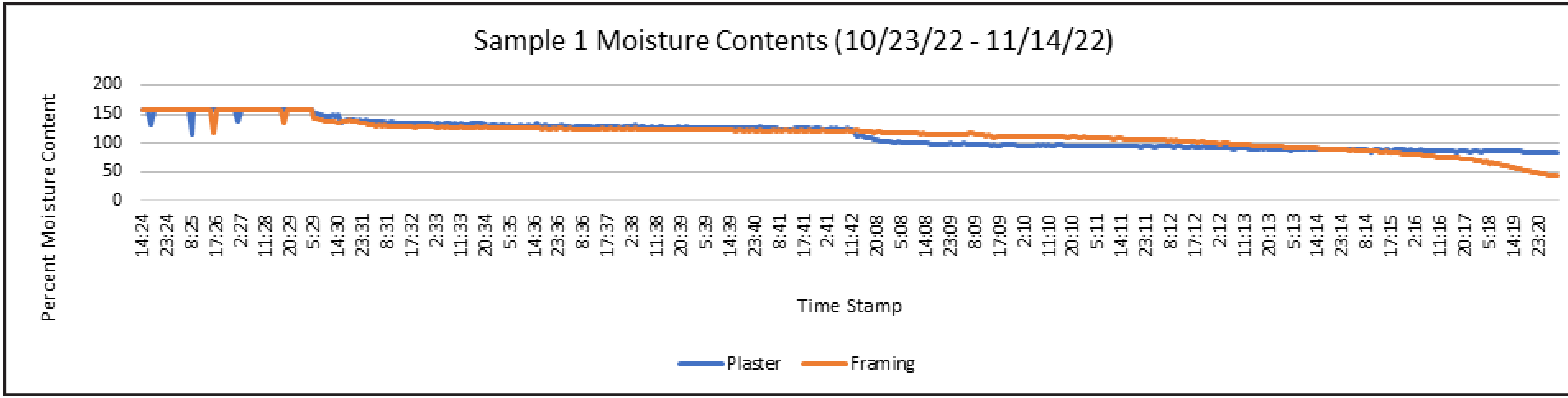
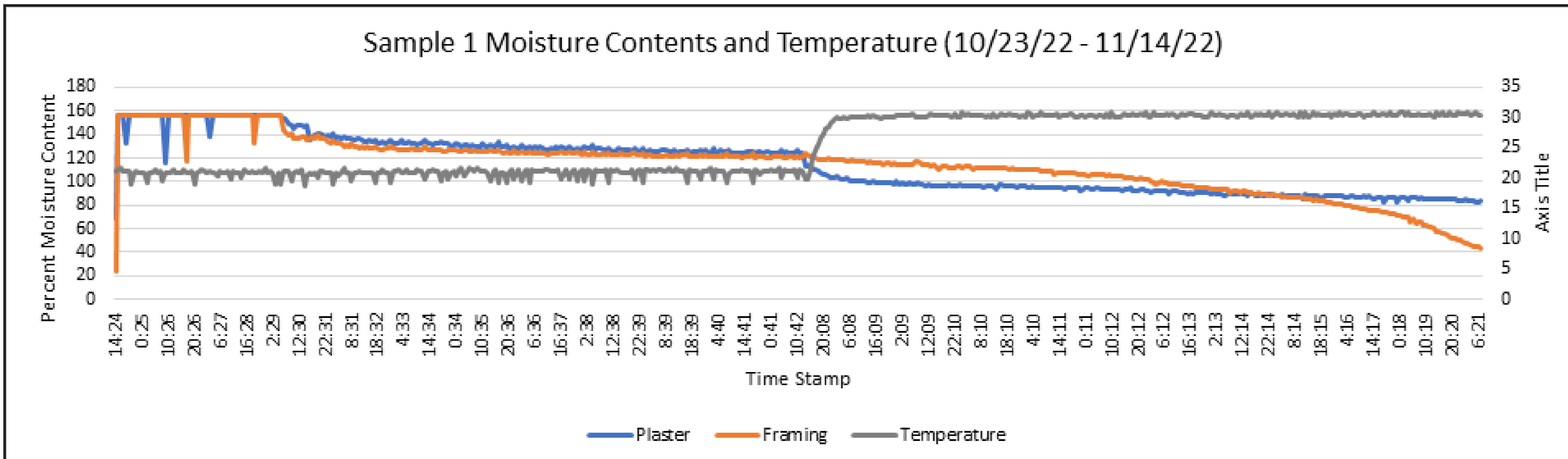
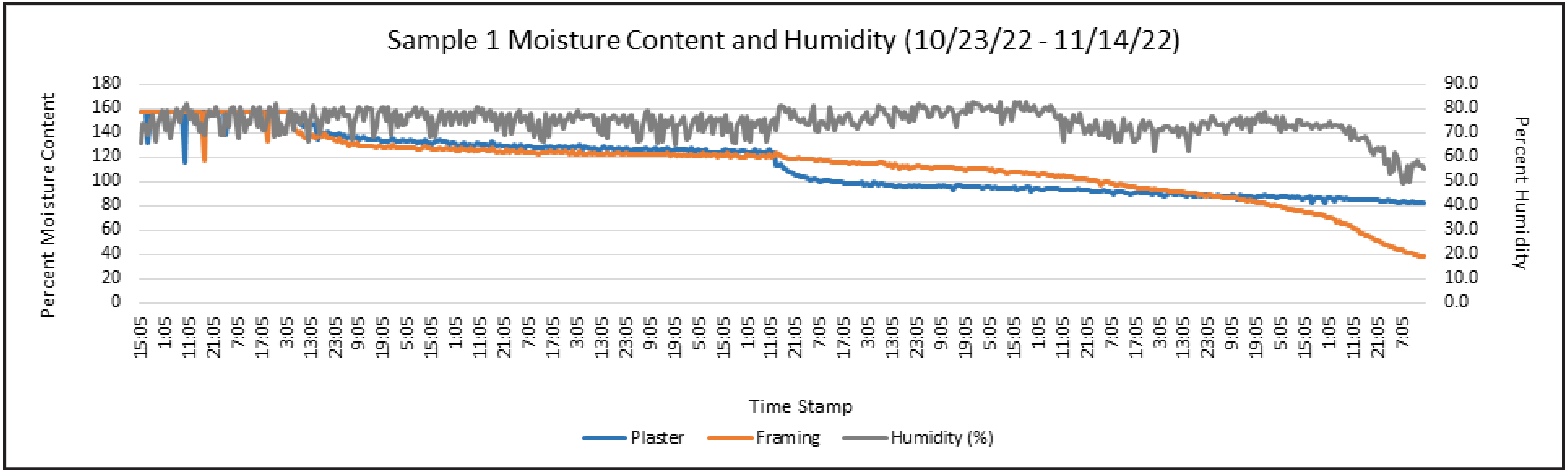
GRAPHS CONTINUE ON NEXT PAGE


Sample 1 Moisture Contents (10/23/22 - 11/14/22)
Percent Moisture Content
200
150
100
50
0
Time Stamp
Plaster
Framing


Sample 1 Moisture Contents and Temperature (10/23/22 - 11/14/22)
Percent Moisture Content
180
160
140
120
100
80
60
40
20
0
Axis Title
35
30
25
20
15
10
5
0
Time Stamp
Plaster
Framing
Temperature


Sample 1 Moisture Content and Humidity (10/23/22 - 11/14/22)
Percent Moisture Content
Percent Humidity
Time Stamp
Plaster
Framing
Humidity (%)

Appendix A3: Sample 1 Photographs

Appendix A3 Figure 1 - Sample 1 construction showing taper sawn Southern Yellow Pine siding.

Appendix A3 Figure 2 - Sample 1 construction showing base framing.

Appendix A3 Figure 3 - Sample 1 construction showing plaster.

Appendix A3 Figure 4 - Sample 1 construction section view.

Appendix A3 Figure 5 - Sample 1 construction siding detail.

Appendix A5 Figure 6 - Sample 1 construction with painted siding.

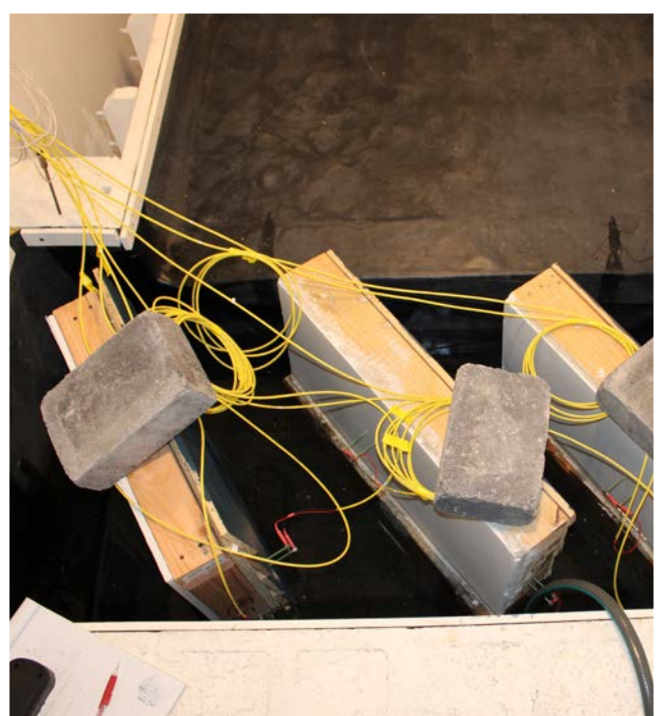
Appendix A3 Figure 7 - Sample 1 final construction oblique section view.

Appendix A3 Figure 8 - Sample 1 final construction section view.

Appendix A3 Figure 9 - Sample 1 final construction plaster.

Appendix A3 Figure 10 - Sample 1 final construction section view detail.

Appendix A3 Figure 11 - Sample 1 (center) in the test chamber with Lignomat probes installed.



Appendix A3 Figure 12 - Sample 1 (center) in the test chamber with Lignomat probes installed and weights in place.

Appendix A3 Figure 13 - Sample 1 showing water level during flooding period.

Appendix A3 Figure 14 - Sample 1 showing height of water absorption post-draining.

Appendix A3 Figure 15 - Sample 1 post-draining detail.

Appendix A3 Figure 16 - Sample 1 crystallized granules on plaster post-draining.

Appendix A3 Figure 17 - Sample 1 during extended drying period.

Appendix A3 Figure 18 - Sample 1 post-drying period.

APPENDIX B: SAMPLE 2 - PLASTER & WIRE LATH

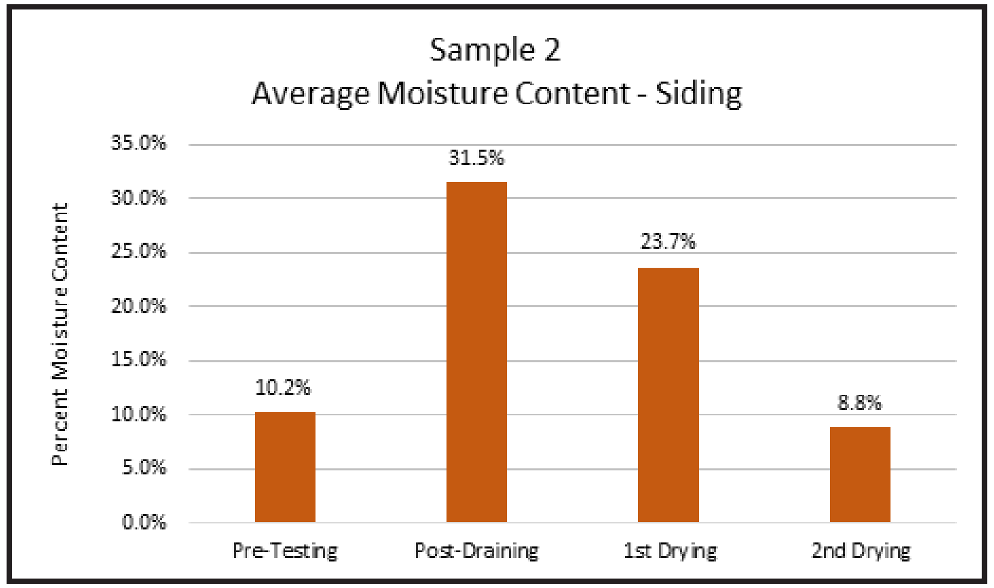
The following pages include the Testing Specimens Record Sheet for the Sample 2 specimen, Sample 2 Results Graphs, and Sample 2 photographs.

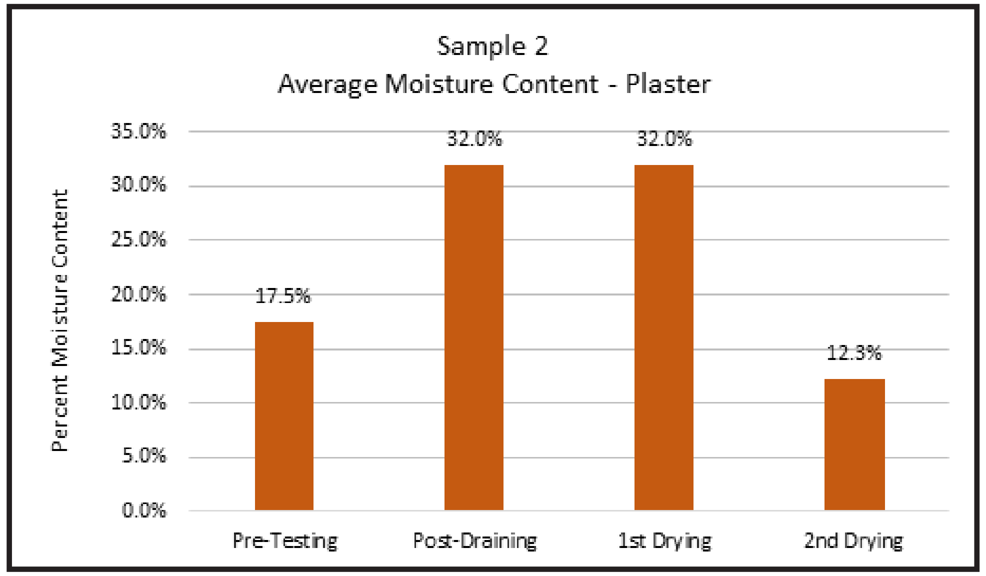
Appendix B1: Sample 2 Specimen Record Sheets

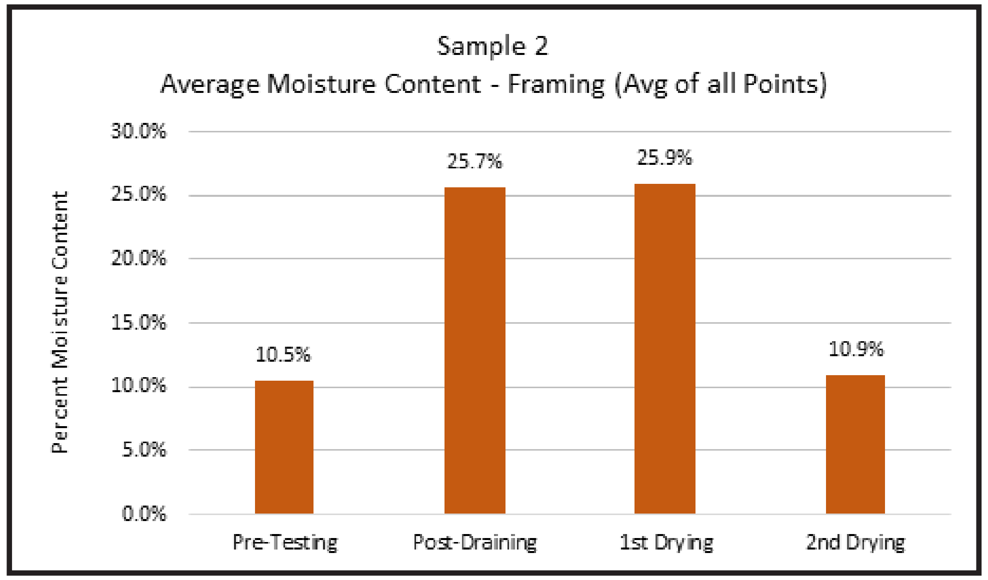
Test Sample Record Sheet					
Test Protocol #	2		Date	10/24/22-11/3/22	
Sample #	2	**Sample Name:**	Wall System - Plaster with Wire Lath		
Pre-Test Characteristics					AVG
Moisture Content					
Siding		**1**	**2**	**3**	
		10.0%	10.3%	6.5%	**10.2%**
Framing	**Top**	**Right End**	**Left End**		
		10.7%	10.3%		**10.5%**
	Right Side	**Top**	**Bottom**		
		10.1%	10.4%		**10.3%**
	Left Side	**Top**	**Bottom**		
		10.5%	10.9%		**10.7%**
Plaster		**1**	**2**	**3**	
		21.0%	18.0%	31.0%	**17.5%**
Thickness (inches)					
Siding		**1**	**2**		
		1.00	1.00		**1**
Wall		**1**	**2**		
		6.00	6.00		**6**
Post-Draining Test Characteristics					AVG
Moisture Content					
Siding		**1**	**2**		
		32.0%	31.0%		**31.5%**
Framing	**Top**	**Right End**	**Left End**		
		12.3%	12.5%		**12.4%**
	Right Side	**Top**	**Bottom**		
		32.3%	32.4%		**32.4%**
	Left Side	**Top**	**Bottom**		
		31.4%	33.0%		**32.2%**
Plaster		**1**	**2**		
		32.0%	32.0%		**32.0%**
Thickness (inches)					
Siding		**1**	**2**		
		1.18	1.17		**1.18**
Wall		**1**	**2**		
		6.07	6.10		**6.09**

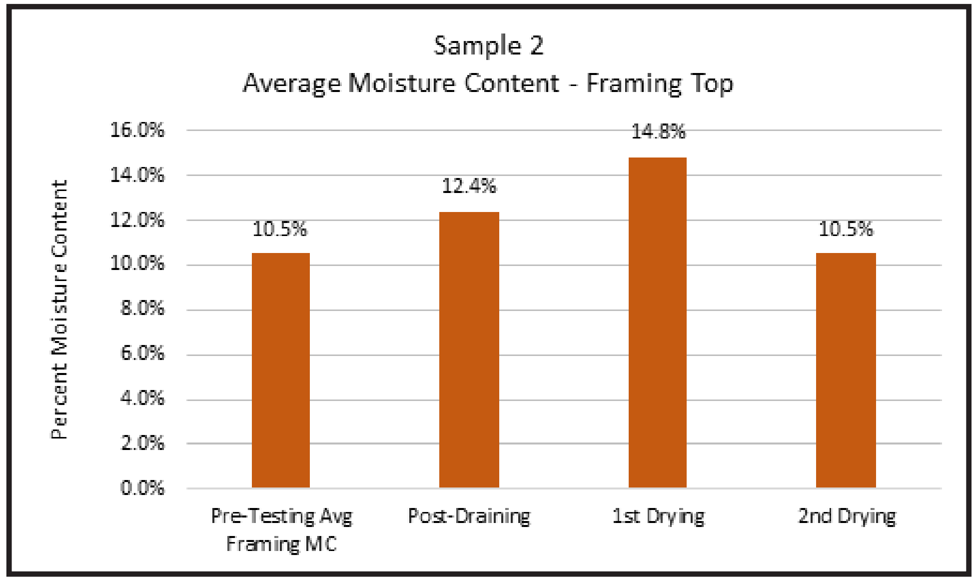
Test Sample Record Sheet, Continued					
Test Protocol #	2		Date	10/24/22-11/3/22	
Sample #	2	**Sample Name:**	Wall System - Plaster with Wire Lath		
Post-First Drying Period Characteristics					AVG
Moisture Content					
Siding		**1**	**2**	**3**	
		24.0%	23.0%	24.0%	**23.7%**
Framing	**Top**	**Right End**	**Left End**		
		14.6%	15.0%		**14.8%**
	Right Side	**Top**	**Bottom**		
		32.0%	30.0%		**31.0%**
	Left Side	**Top**	**Bottom**		
		32.0%	32.0%		**32.0%**
Plaster		**1**	**2**		
		32.0%	32.0%		**32.0%**
Thickness (inches)					
Siding		**1**	**2**		
		1.06	1.06		**1.06**
Wall		**1**	**2**		
		6.06	6.06		**6.06**
Post-Second Drying Period Characteristics					AVG
Moisture Content					
Siding		**1**	**2**		
		8.5%	9.0%		**8.8%**
Framing	**Top**	**Right End**	**Left End**		
		10.0%	11.0%		**10.5%**
	Right Side	**Top**	**Bottom**		
		9.0%	13.0%		**11.0%**
	Left Side	**Top**	**Bottom**		
		8.5%	14.0%		**11.3%**
Plaster		**1**	**2**		
		12.5%	12.0%		**12.3%**
Thickness (inches)					
Siding		**1**	**2**		
		1.06	1.06		**1.06**
Wall		**1**	**2**		
		6.00	6.00		**6.00**

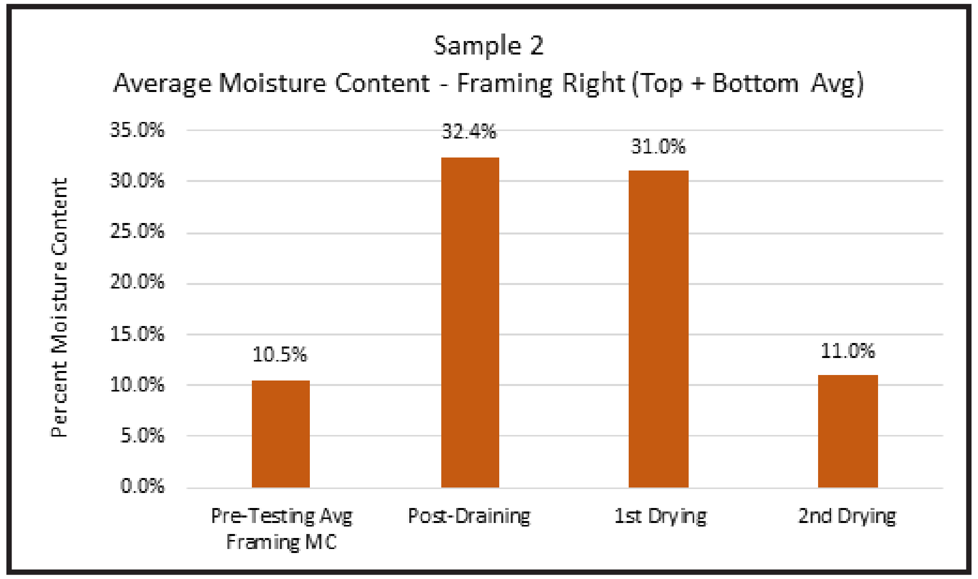
Appendix B2: Sample 2 Results Graphs

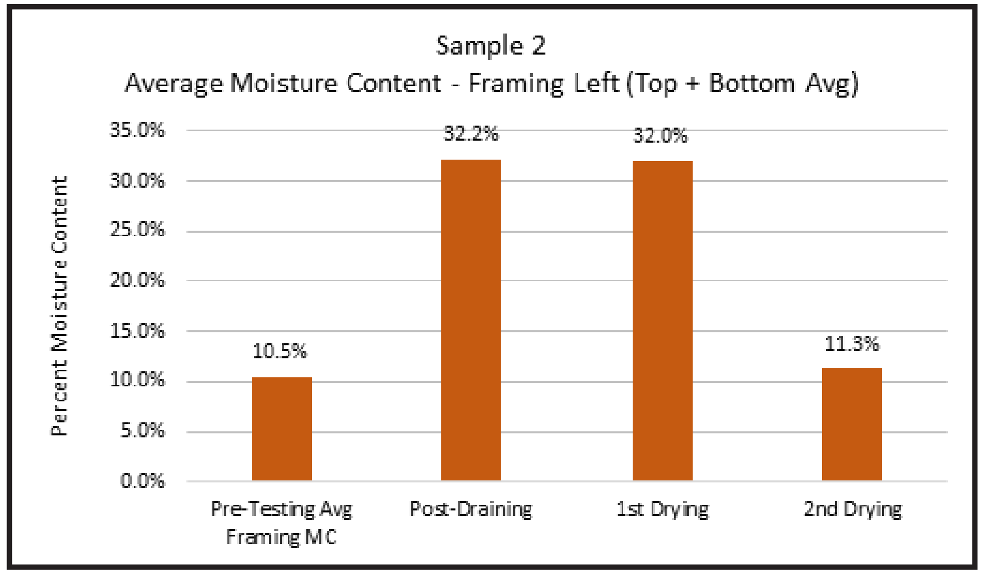


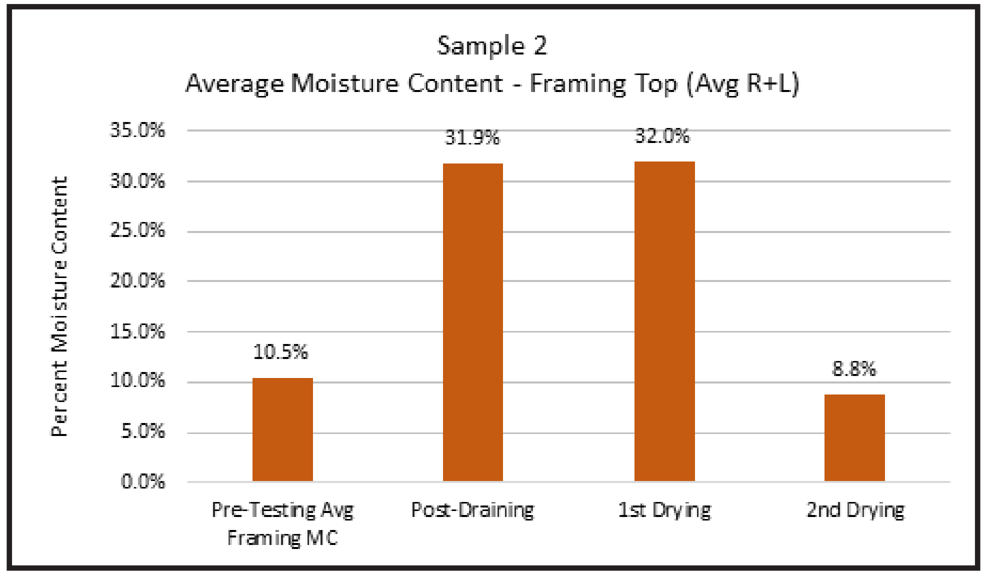


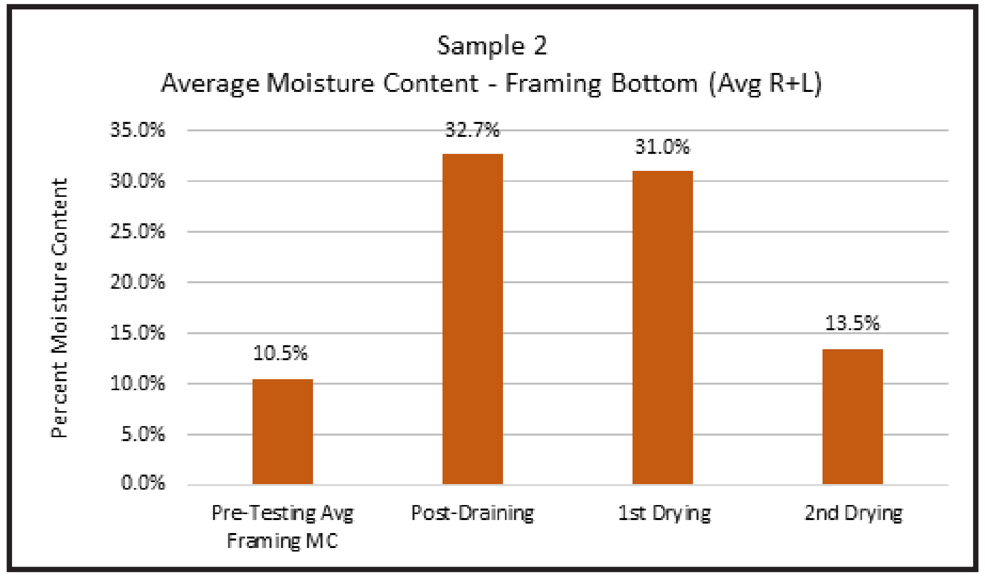


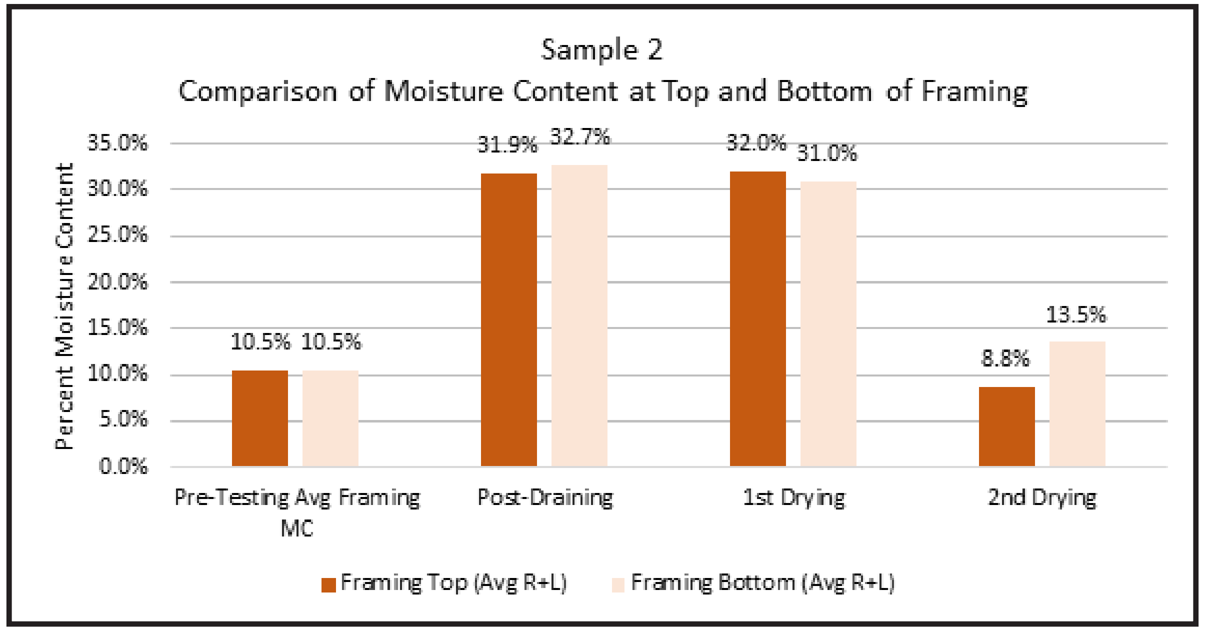


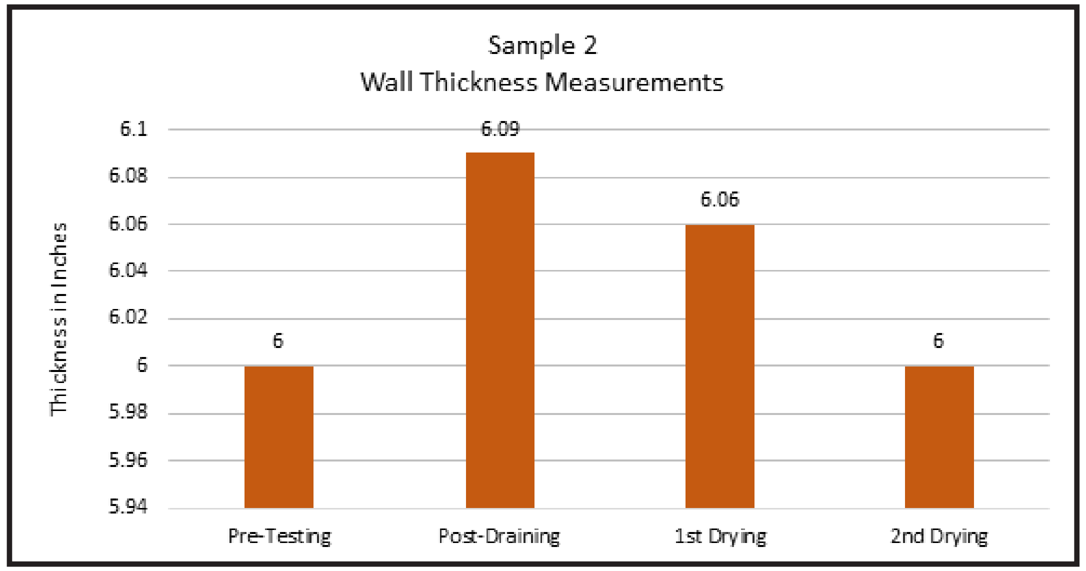


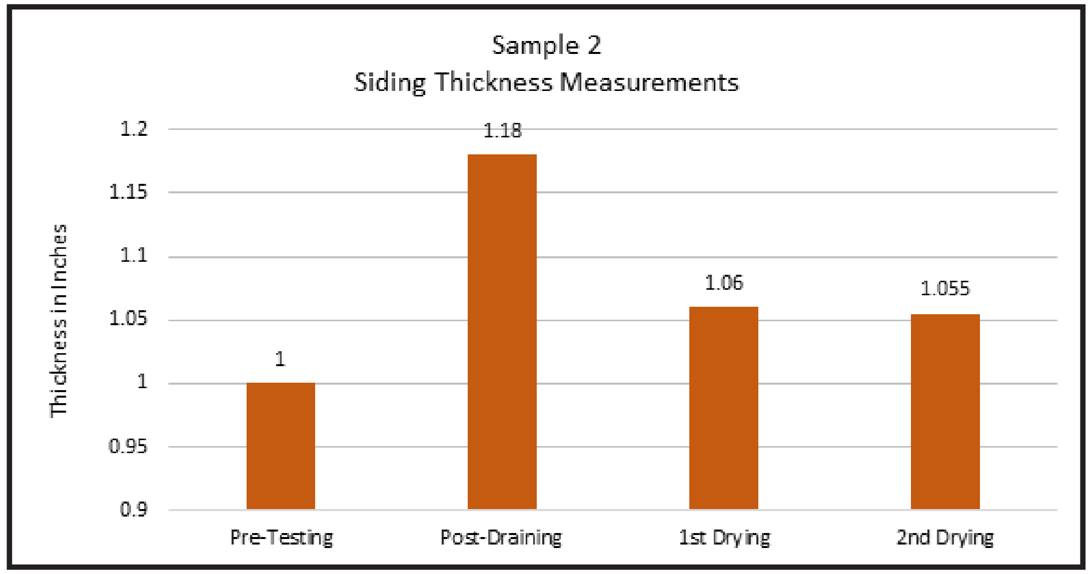


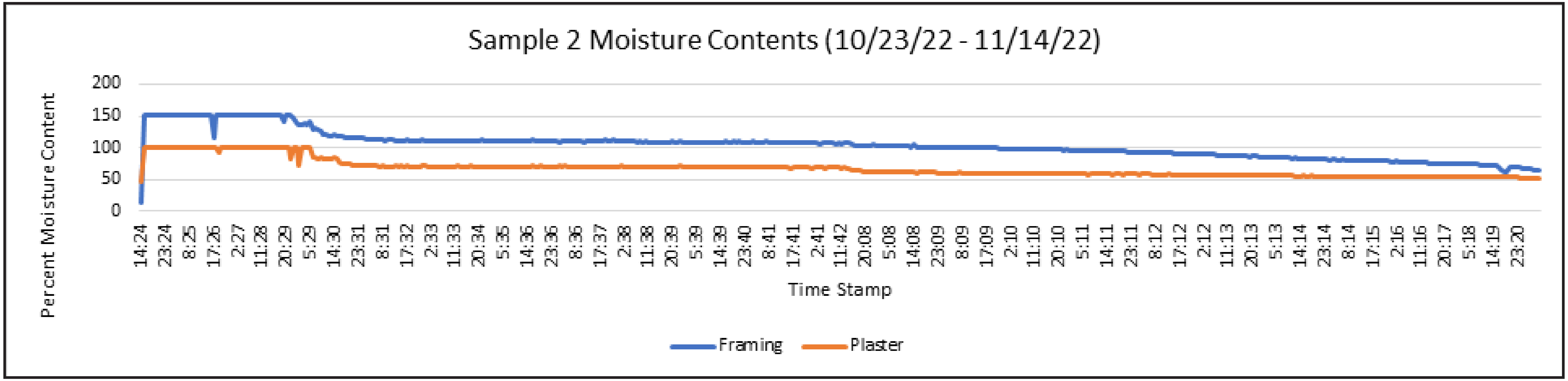

Sample 2
Average Moisture Content - Framing Top (Avg R+L)
Percent Moisture Content
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
10.5%
31.9%
32.0%
8.8%
Pre-Testing Avg Framing MC
Post-Draining
1st Drying
2nd Drying

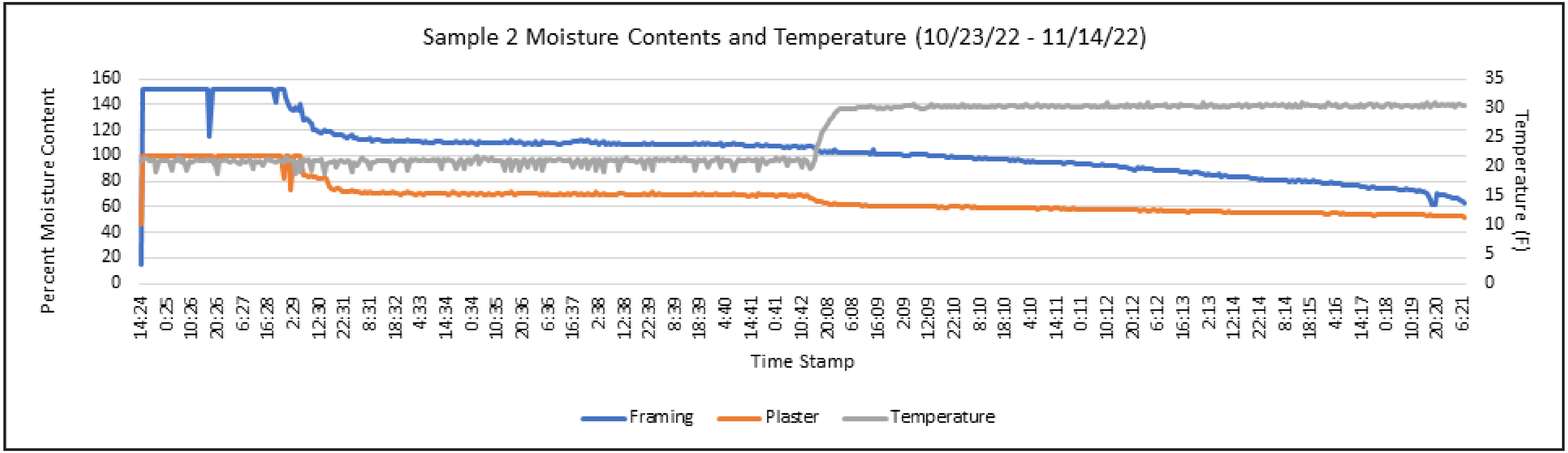

Sample 2
Average Moisture Content - Framing Bottom (Avg R+L)
Percent Moisture Content
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
10.5%
32.7%
31.0%
13.5%
Pre-Testing Avg Framing MC
Post-Draining
1st Drying
2nd Drying

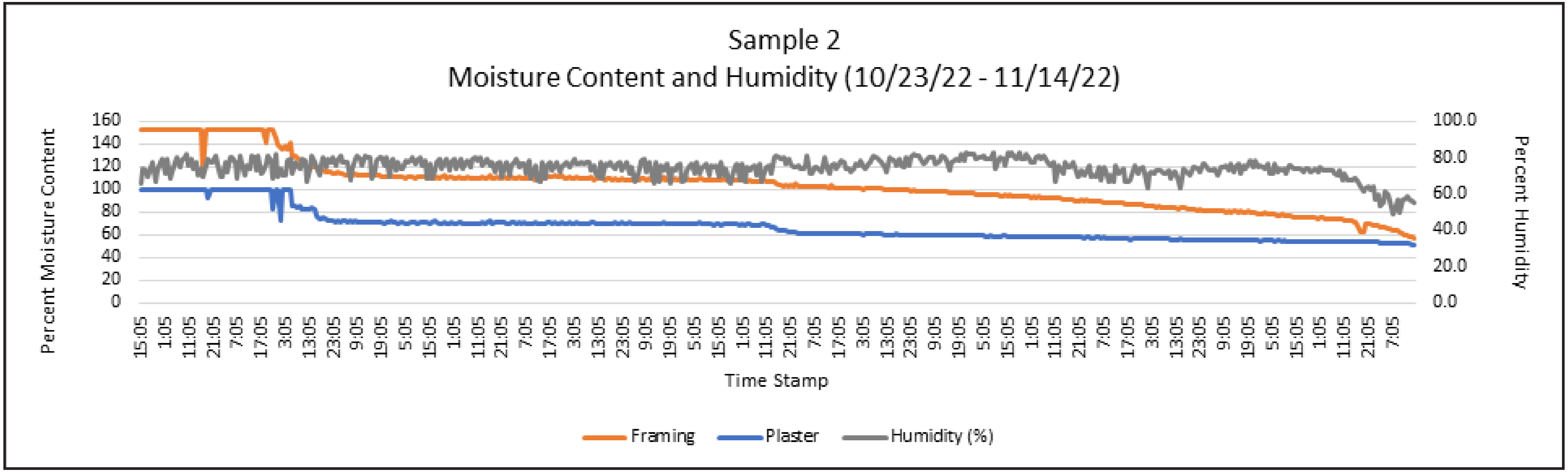

Sample 2
Comparison of Moisture Content at Top and Bottom of Framing
Percent Moisture Content
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
10.5% 10.5%
31.9% 32.7%
32.0% 31.0%
8.8% 13.5%
Pre-Testing Avg Framing MC
Post-Draining
1st Drying
2nd Drying
Framing Top (Avg R+L)
Framing Bottom (Avg R+L)


Sample 2
Wall Thickness Measurements
Thickness in Inches
6.1
6.08
6.06
6.04
6.02
6
5.98
5.96
5.94
6
6.09
6.06
6
Pre-Testing
Post-Draining
1st Drying
2nd Drying


Sample 2
Siding Thickness Measurements
Thickness in Inches
1.2
1.15
1.1
1.05
1
0.95
0.9
1
1.18
1.06
1.055
Pre-Testing
Post-Draining
1st Drying
2nd Drying


Sample 2 Moisture Contents (10/23/22 - 11/14/22)
Percent Moisture Content
Time Stamp
Framing
Plaster


Sample 2 Moisture Contents and Temperature (10/23/22 - 11/14/22)
Percent Moisture Content
Temperature (F)
Time Stamp
Framing
Plaster
Temperature


Sample 2
Moisture Content and Humidity (10/23/22 - 11/14/22)
Percent Moisture Content
160
140
120
100
80
60
40
20
0
100.0
80.0
60.0
40.0
20.0
0.0
Percent Humidity
15:05
1:05
11:05
21:05
7:05
17:05
3:05
13:05
23:05
9:05
19:05
5:05
15:05
1:05
11:05
21:05
7:05
17:05
3:05
13:05
23:05
9:05
19:05
5:05
15:05
1:05
11:05
21:05
7:05
17:05
3:05
13:05
23:05
9:05
19:05
5:05
15:05
1:05
11:05
21:05
7:05
17:05
3:05
13:05
23:05
9:05
19:05
5:05
15:05
1:05
11:05
21:05
7:05
Time Stamp
Framing
Plaster
Humidity (%)

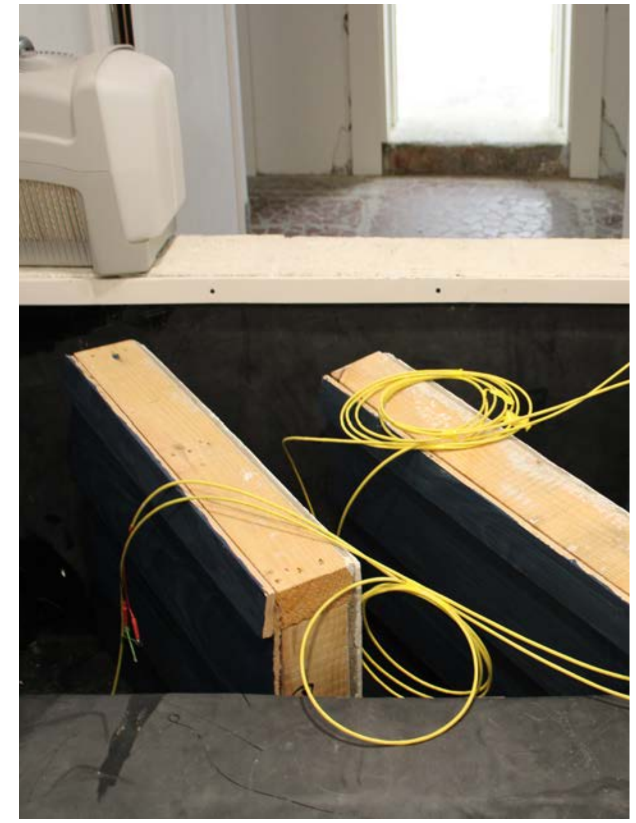
Appendix B3: Sample 2 Photographs

Appendix B3 Figure 1 - Sample 2 construction showing plaster.

Appendix B3 Figure 2 - Sample 2 construction showing bottom framing.

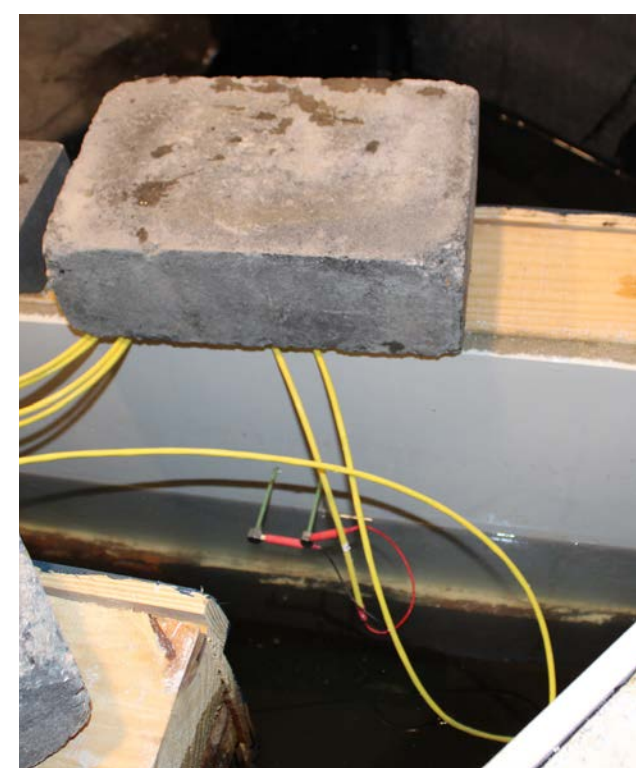
Appendix B3 Figure 3 - Sample 2 construction section view.

Appendix B4 Figure 4 - Sample 2 construction showing painted taper sawn Southern Yellow Pine siding.

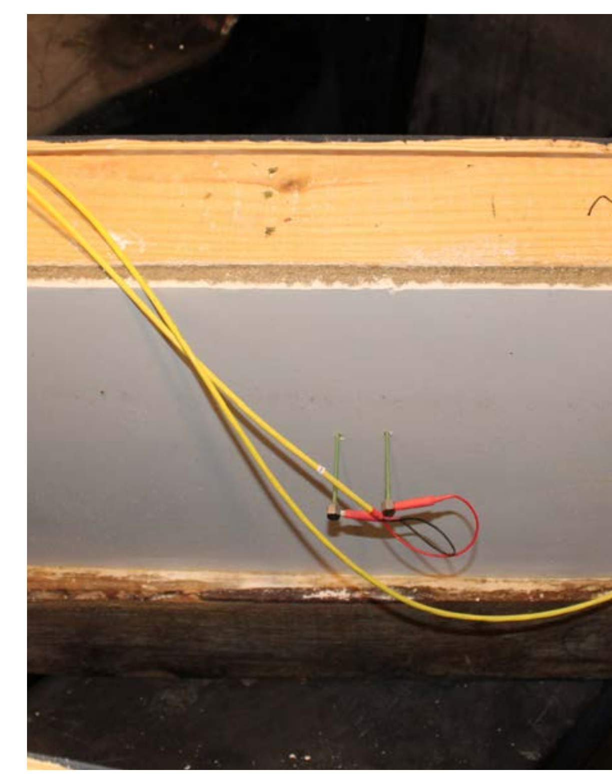


Appendix B3 Figure 5 - Sample 2 (left) in test chamber with Lignomat probes installed.

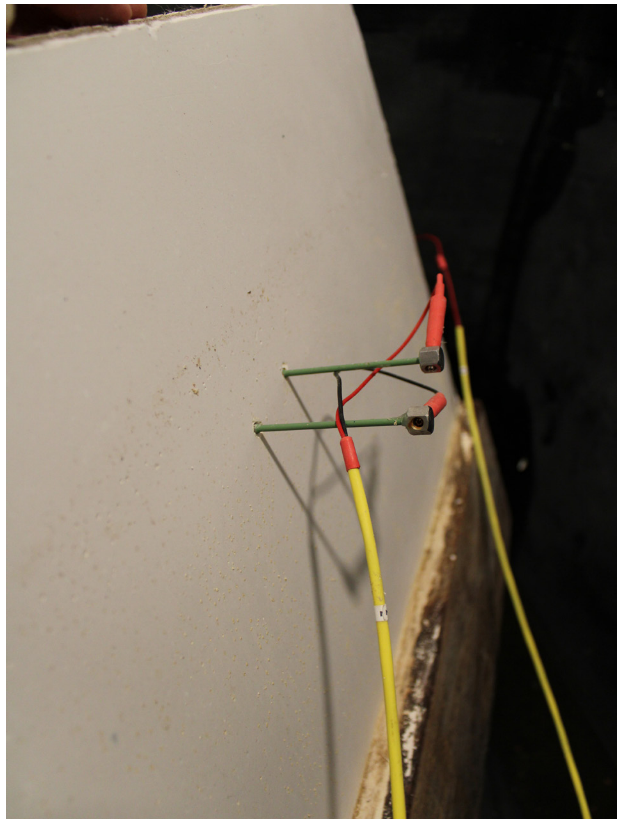
Appendix B3 Figure 6 - Sample 2 (right) in test chamber during flooding period with weights.



Appendix B3 Figure 7 - Sample 2 showing water level during flooding period.

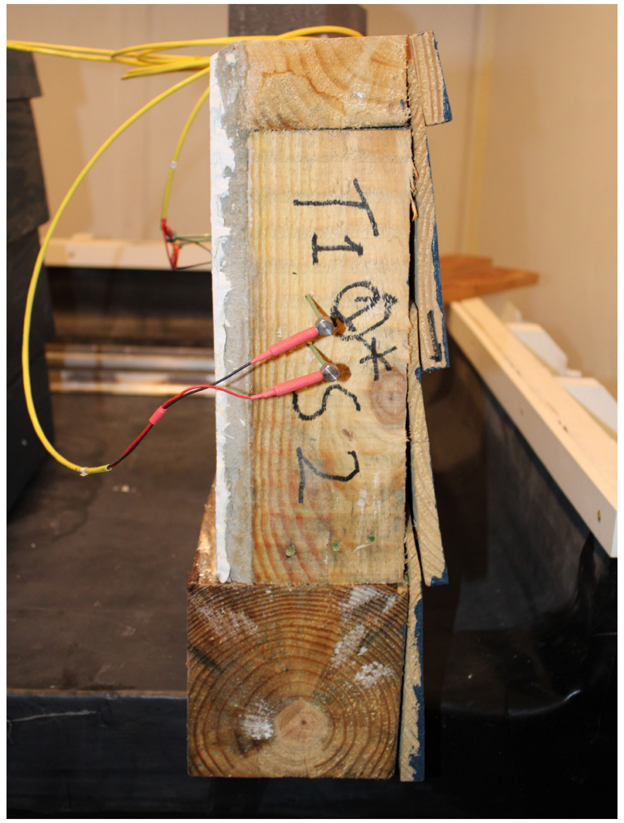


Appendix B4 Figure 8 - Sample 2 post-draining.



Appendix B3 Figure 9 - Sample 2 showing crystallized granules after draining.

Appendix B3 Figure 11 - Sample 2 after the extended drying period.



Appendix B3 Figure 10 - Sample 2 during the extended drying period.

Appendix B4 Figure 12 - Sample 2 section view after the extended drying period.

Appendix B3 Figure 13 - Sample 2 showing warping of siding after drying period against a straight edge.

APPENDIX C: SAMPLE 3 - DRYWALL

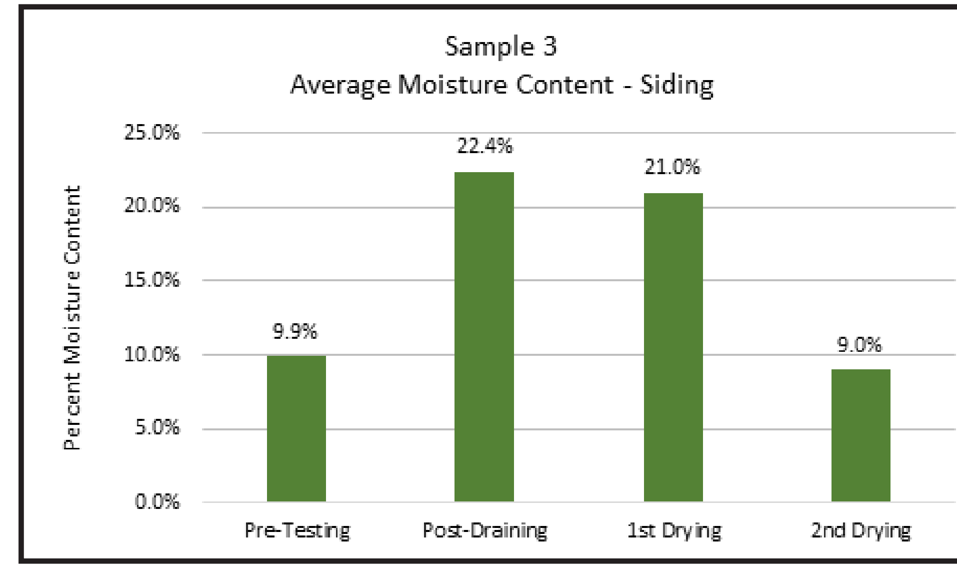
The following pages include the the Testing Specimens Record Sheet for the Sample 3 specimen, Sample 3 Results Graphs, and Sample 3 photographs.

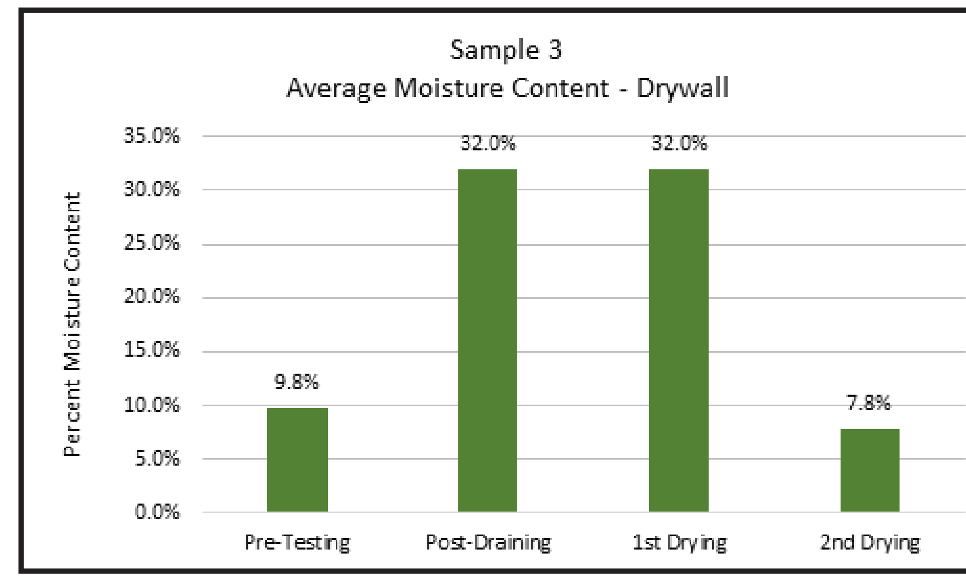
Appendix C1: Sample 3 Specimen Record Sheets

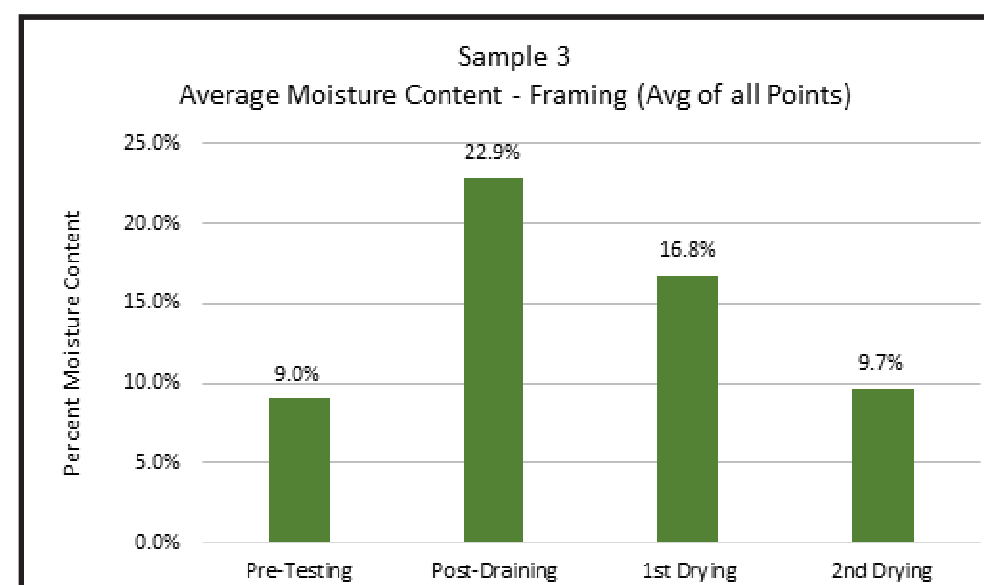
Test Sample Record Sheet					
Test Protocol #	2		Date	10/24/22-11/3/22	
Sample #	3	**Sample Name:**	Wall System - Drywall		
Pre-Test Characteristics					**AVG**
Moisture Content					
Siding		**1**	**2**	**3**	
		9.8%	9.9%	9.9%	**9.9%**
Framing	**Top**	**Right End**	**Left End**		
		8.9%	8.9%		**8.9%**
	Right Side	**Top**	**Bottom**		
		9.5%	9.8%		**9.7%**
	Left Side	**Top**	**Bottom**		
		9.8%	9.6%		**9.7%**
Drywall		**1**	**2**	**3**	
		9.8%	9.9%	9.8%	**9.8%**
Thickness (inches)					
Siding		**1**	**2**	**3**	
		1.00	1.00	1.06	**1.02**
Wall		**1**	**2**	**3**	
		5.94	5.81	5.81	**5.85**
Post-Draining Test Characteristics					**AVG**
Moisture Content					
Siding		**1**	**2**		
		12.8%	32.0%		**22.4%**
Framing	**Top**	**Right End**	**Left End**		
		13.8%	13.9%		**13.9%**
	Right Side	**Top**	**Bottom**		
		13.8%	31.6%		**22.7%**
	Left Side	**Top**	**Bottom**		
		32.0%	32.0%		**32.0%**
Drywall		**1**	**2**		
		32.0%	32.0%		**32.0%**
Thickness (inches)					
Siding		**1**	**2**		
		1.08	1.06		**1.07**
Wall		**1**	**2**		
		5.99	5.98		**5.99**

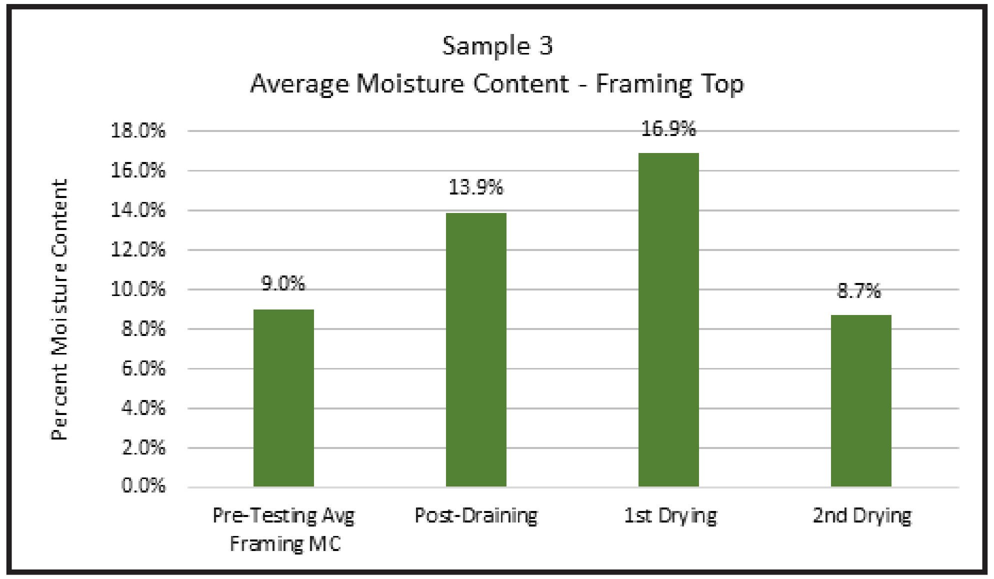
Test Sample Record Sheet, Continued					
Test Protocol #	2		Date	10/24/22-11/3/22	
Sample #	3	Sample Name:	Wall System - Drywall		
Post-First Drying Period Characteristics					**AVG**
Moisture Content					
Siding		**1**	**2**		
		21.0%	21.0%		**21.0%**
Framing	**Top**	**Right End**	**Left End**		
		16.8%	16.9%		**16.9%**
	Right Side	**Top**	**Bottom**		
		12.8%	21.0%		**16.9%**
	Left Side	**Top**	**Bottom**		
		13.0%	20.0%		**16.5%**
Drywall		**1**	**2**		
		32.0%	32.0%		**32.0%**
Thickness (inches)					
Siding		**1**	**2**		
		1.00	1.00		**1.00**
Wall		**1**	**2**		
		6.00	6.00		**6.00**
Post-Second Drying Period Characteristics					**AVG**
Moisture Content					
Siding		**1**	**2**		
		8.9%	9.0%		**9.0%**
Framing	**Top**	**Right End**	**Left End**		
		8.4%	9.0%		**8.7%**
	Right Side	**Top**	**Bottom**		
		9.0%	11.0%		**10.0%**
	Left Side	**Top**	**Bottom**		
		8.5%	12.0%		**10.3%**
Drywall		**1**	**2**		
		7.6%	8.0%		**7.8%**
Thickness (inches)					
Siding		**1**	**2**		
		0.94	0.94		**0.94**
Wall		**1**	**2**		
		5.94	5.94		**5.94**

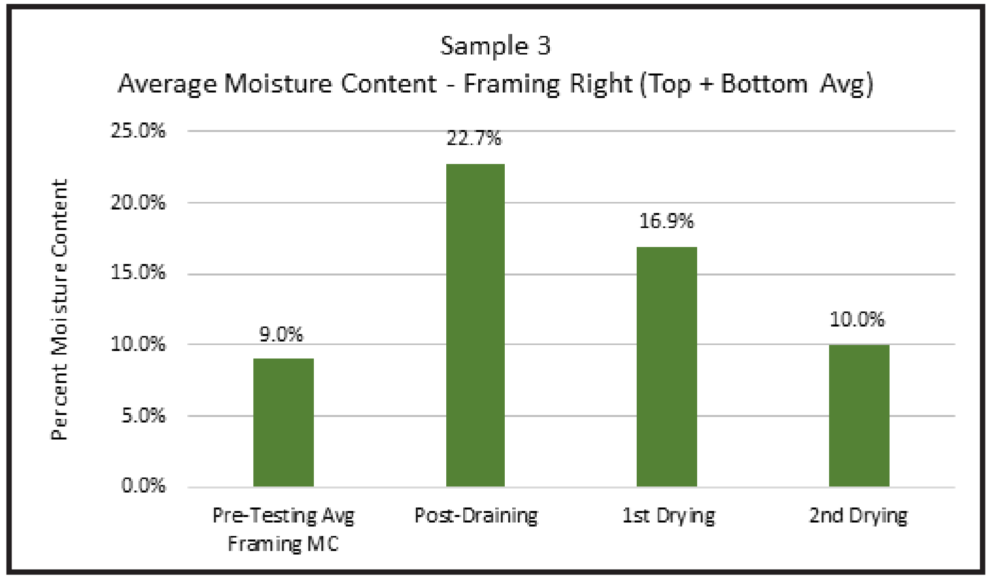
Appendix C2: Sample 3 Results Graphs

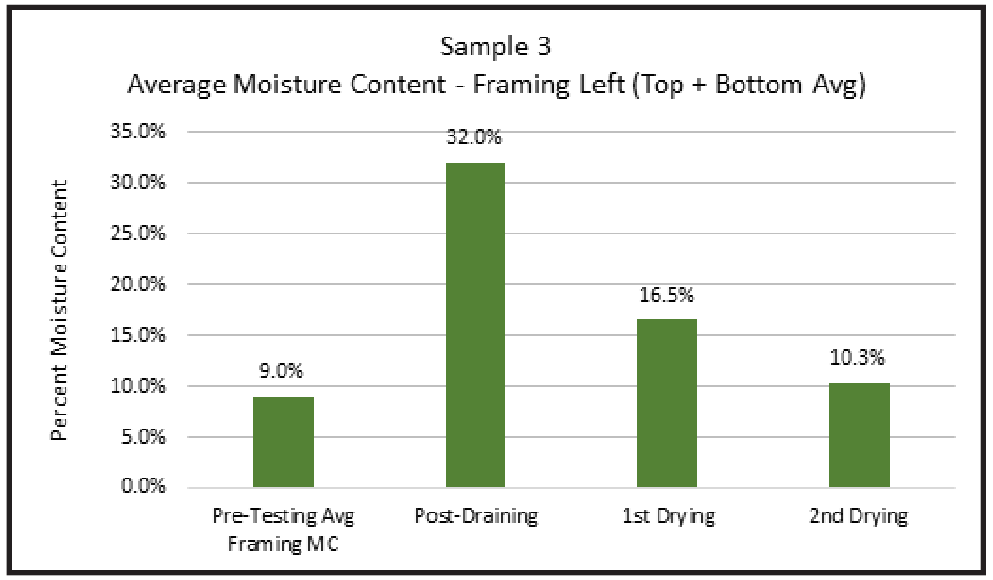


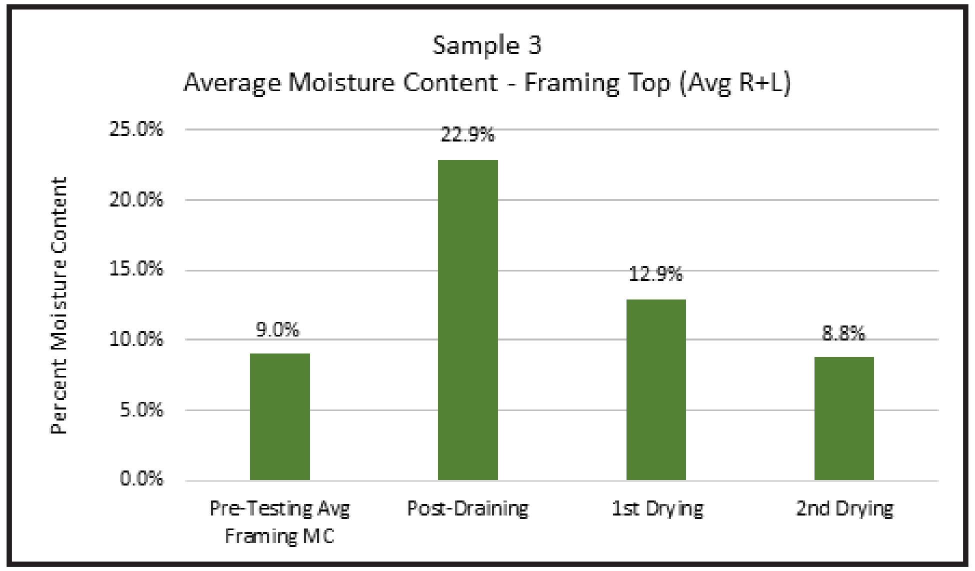


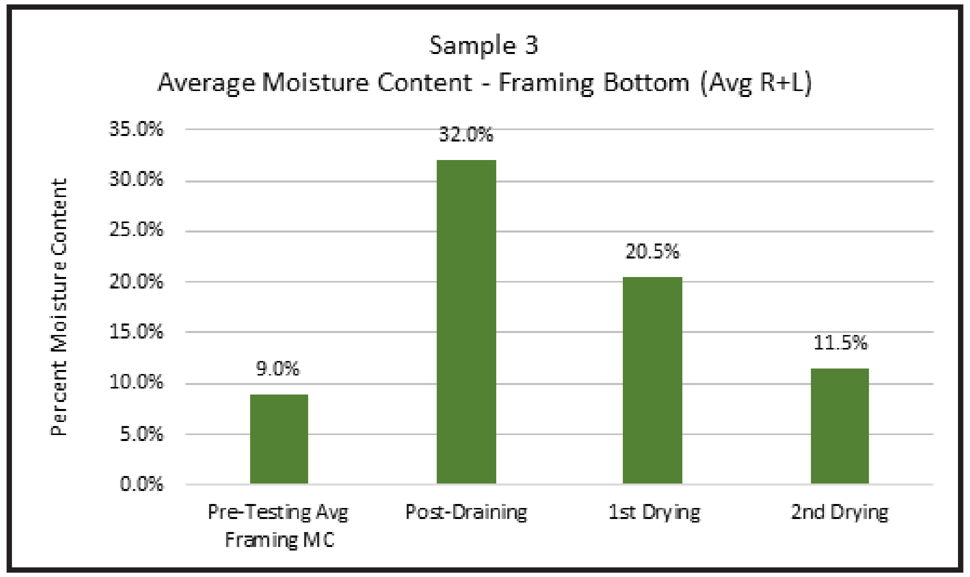


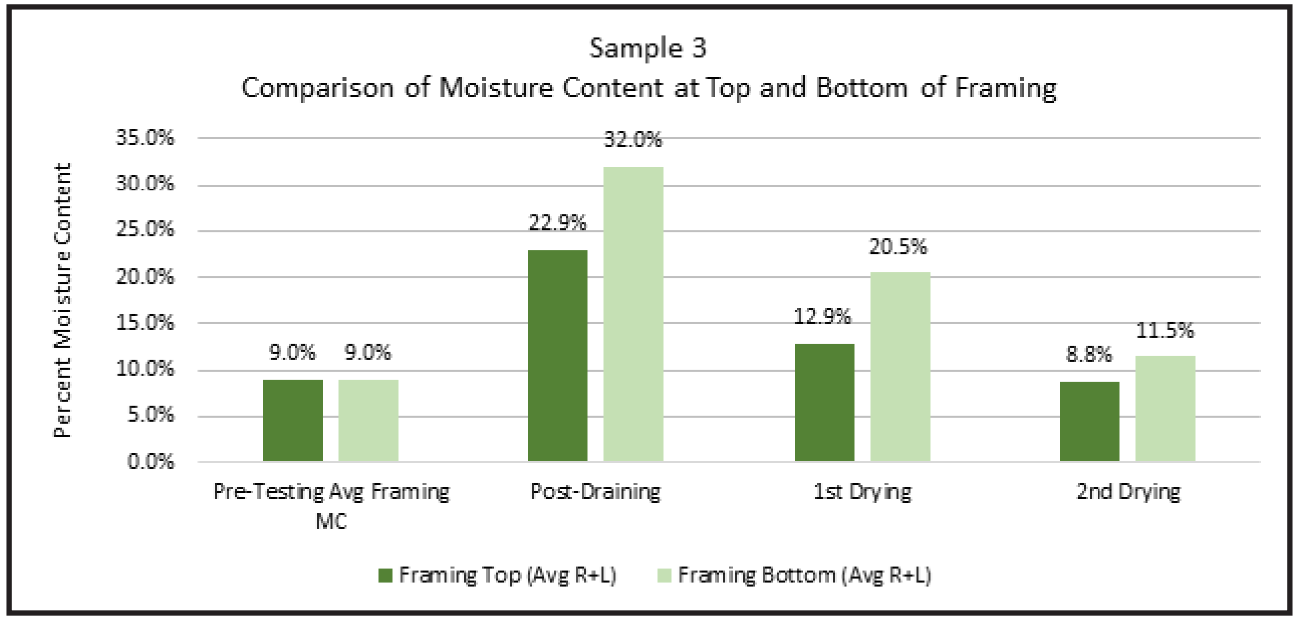

Sample 3
Average Moisture Content - Framing Top
Percent Moisture Content
18.0%
16.0%
14.0%
12.0%
10.0%
8.0%
6.0%
4.0%
2.0%
0.0%
9.0%
13.9%
16.9%
8.7%
Pre-Testing Avg Framing MC
Post-Draining
1st Drying
2nd Drying

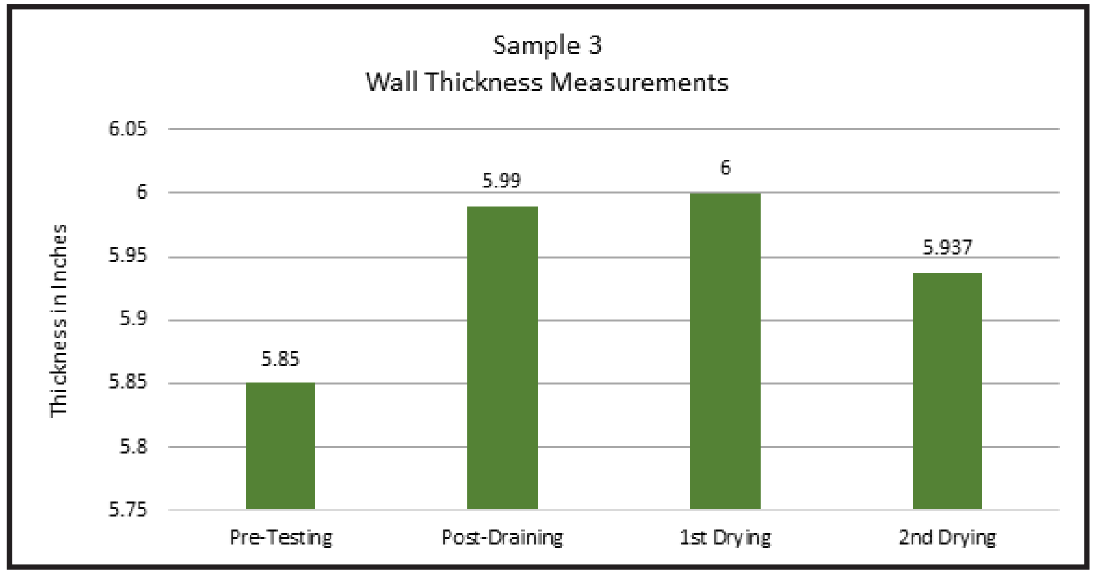

Sample 3
Average Moisture Content - Framing Right (Top + Bottom Avg)
Percent Moisture Content
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
9.0%
22.7%
16.9%
10.0%
Pre-Testing Avg Framing MC
Post-Draining
1st Drying
2nd Drying

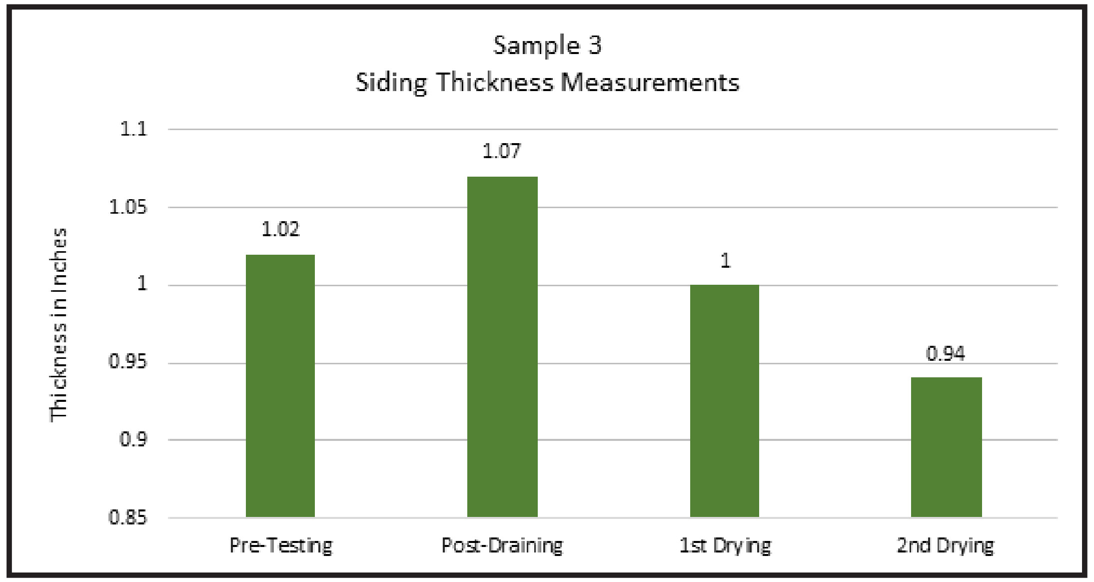

Sample 3
Average Moisture Content - Framing Left (Top + Bottom Avg)
Percent Moisture Content
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
9.0%
32.0%
16.5%
10.3%
Pre-Testing Avg Framing MC
Post-Draining
1st Drying
2nd Drying


Sample 3
Average Moisture Content - Framing Top (Avg R+L)
Percent Moisture Content
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
9.0%
22.9%
12.9%
8.8%
Pre-Testing Avg Framing MC
Post-Draining
1st Drying
2nd Drying


Sample 3
Average Moisture Content - Framing Bottom (Avg R+L)
Percent Moisture Content
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
9.0%
32.0%
20.5%
11.5%
Pre-Testing Avg Framing MC
Post-Draining
1st Drying
2nd Drying


Sample 3
Comparison of Moisture Content at Top and Bottom of Framing
Percent Moisture Content
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
9.0%
9.0%
22.9%
32.0%
12.9%
20.5%
8.8%
11.5%
Pre-Testing Avg Framing MC
Post-Draining
1st Drying
2nd Drying
Framing Top (Avg R+L)
Framing Bottom (Avg R+L)





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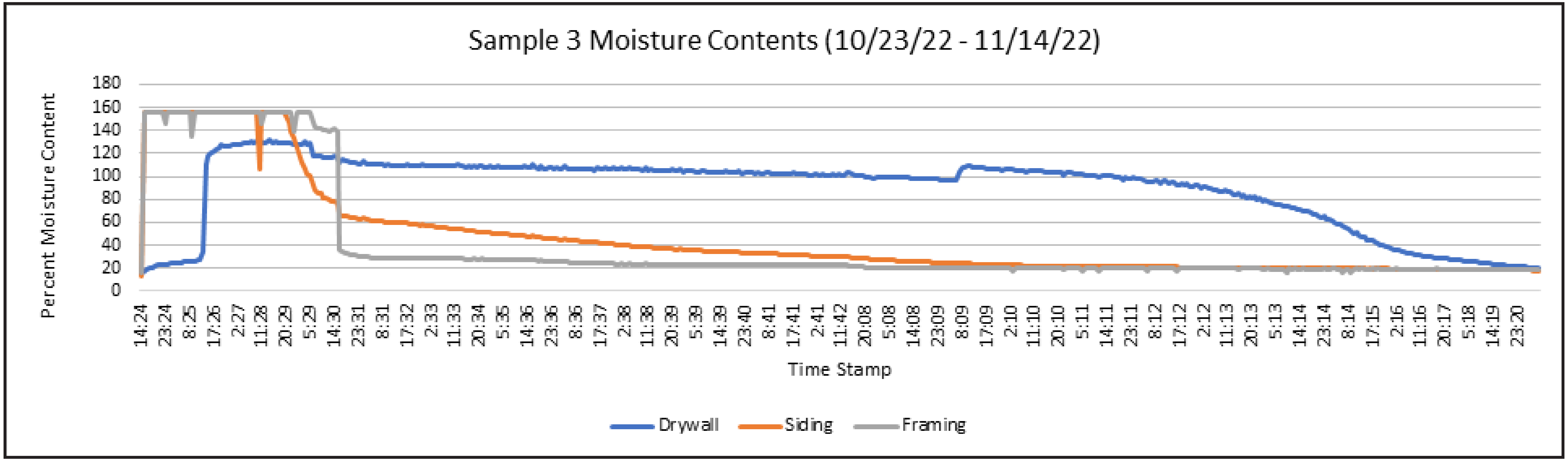
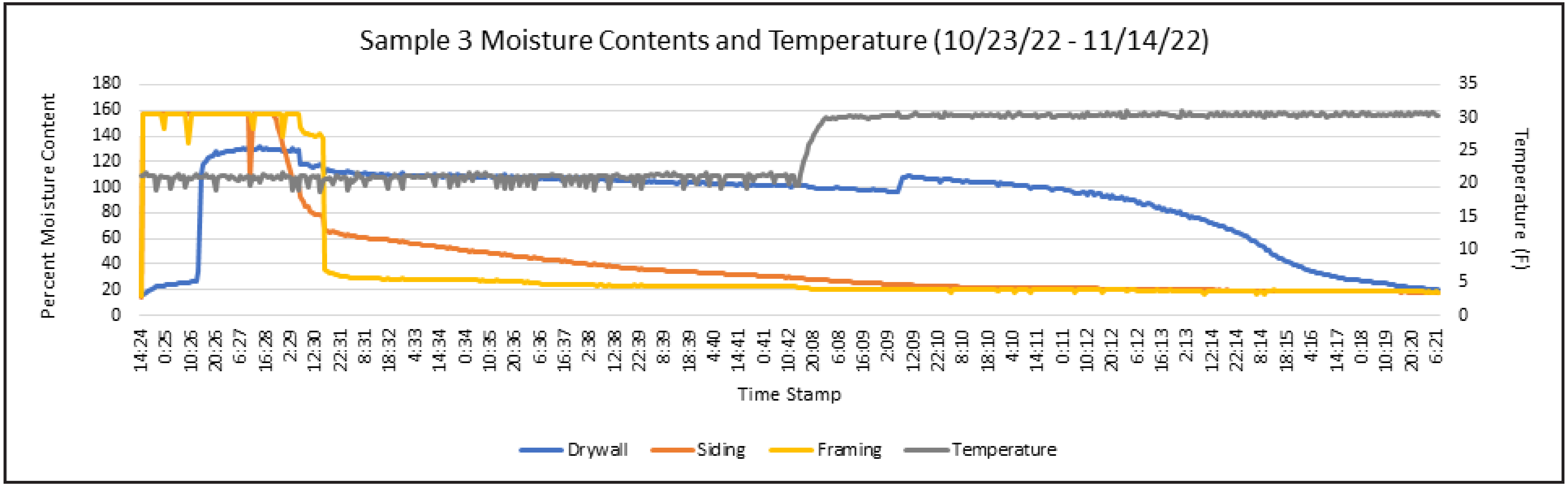
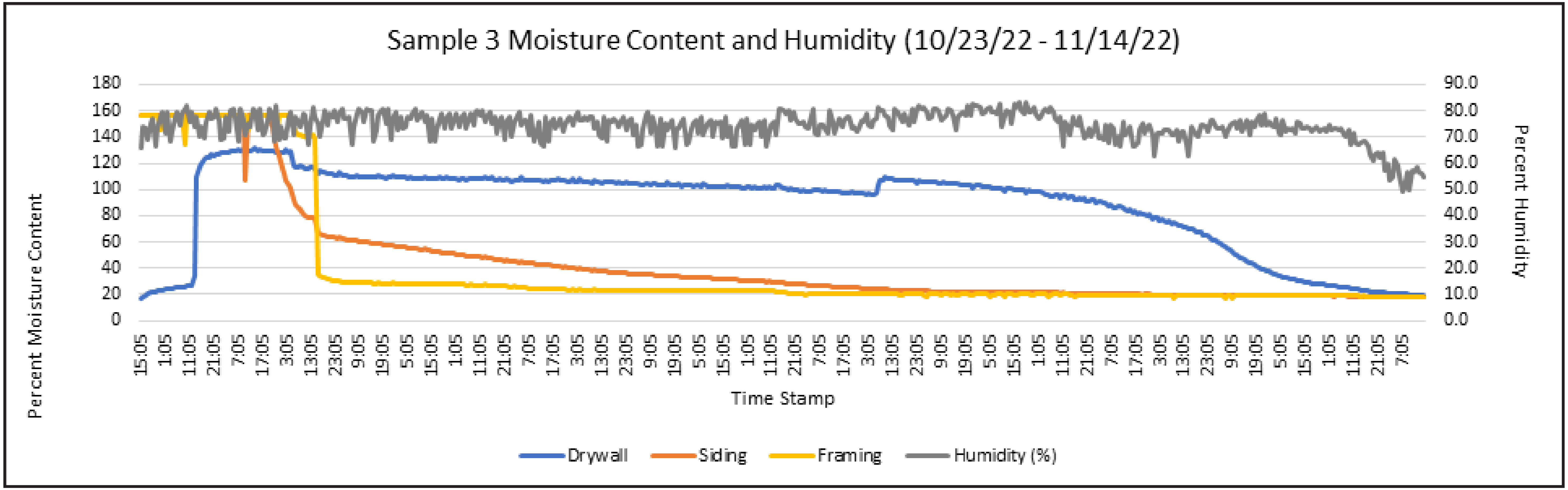
GRAPHS CONTINUE ON NEXT PAGE



Sample 3 Moisture Contents (10/23/22 - 11/14/22)
Percent Moisture Content
Time Stamp
Drywall
Siding
Framing



Sample 3 Moisture Contents and Temperature (10/23/22 - 11/14/22)
Percent Moisture Content
Temperature (F)
Time Stamp
Drywall
Siding
Framing
Temperature


Sample 3 Moisture Content and Humidity (10/23/22 - 11/14/22)
Percent Moisture Content
Percent Humidity
Time Stamp
180
160
140
120
100
80
60
40
20
0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Drywall
Siding
Framing
Humidity (%)

Appendix C3: Sample 3 Photographs

Appendix C3 Figure 1 - Sample 3 construction showing framing and Oriented Strand Board (OSB).

Appendix C3 Figure 2 - Sample 3 construction showing framing.

Appendix C3 Figure 3 - Sample 3 construction showing Tyvek wrap.

Appendix C3 Figure 3 - Sample 3 construction showing taper sawn Southern Yellow Pine siding.

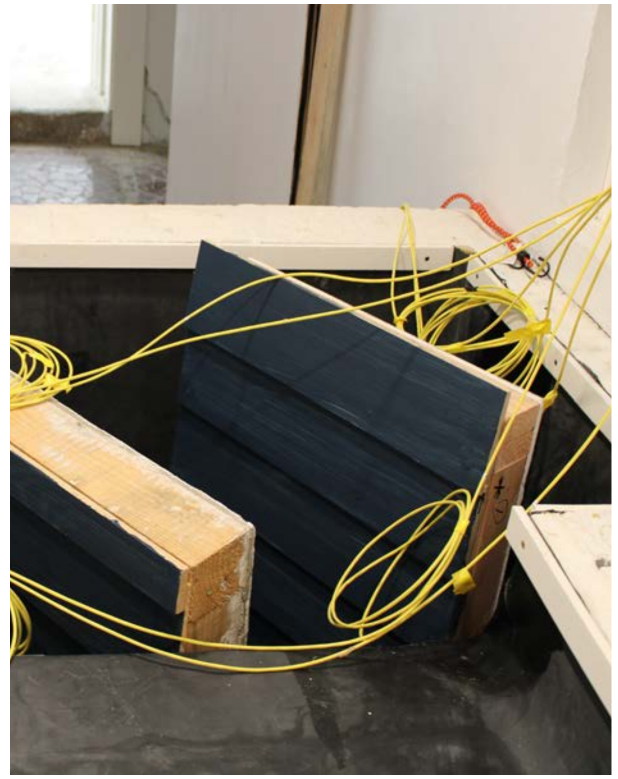
Appendix C3 Figure 5 - Sample 3 construction showing taper sawn Southern Yellow Pine siding.

Appendix C3 Figure 6 - Sample 3 construction showing framing and insulation.

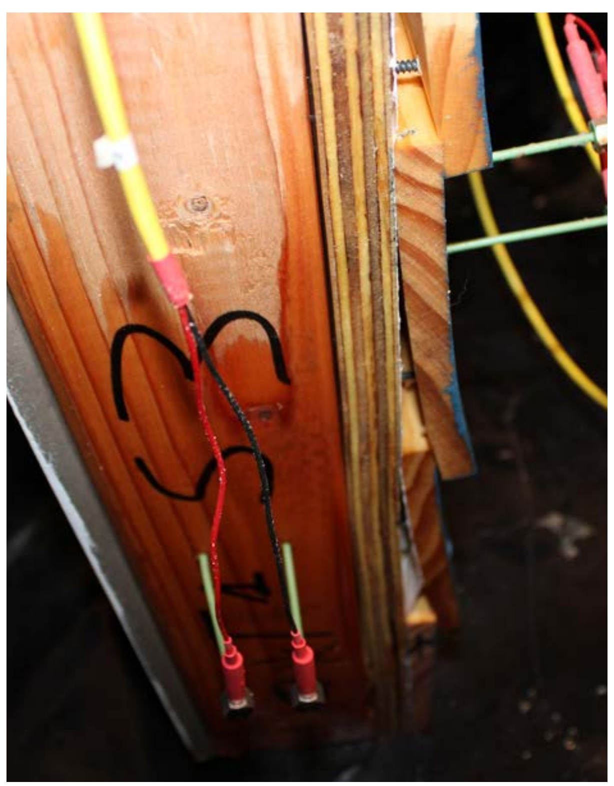
Appendix C3 Figure 7 - Sample 3 construction showing drywall.

Appendix C3 Figure 8 - Sample 3 section view.

Appendix C3 Figure 9 - Sample 3 final construction section view.



Appendix C3 Figure 10 - Sample 3 (right) pre-testing with Lignomat probes installed and samples placed in test chamber.

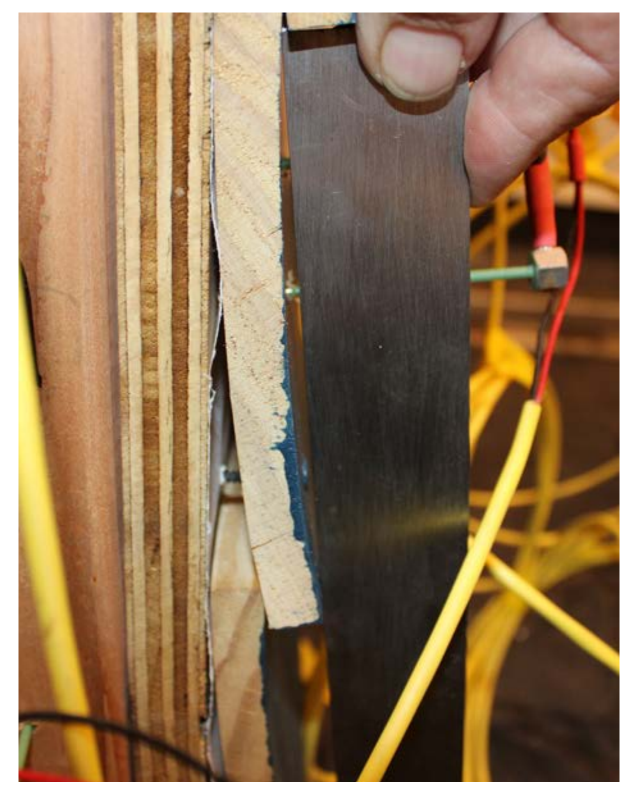


Appendix C3 Figure 11 - Sample 3 post-draining showing wet areas on sample and warped siding.

Appendix C3 Figure 12 - Sample 3 during extended drying period with Lignomat probes installed.

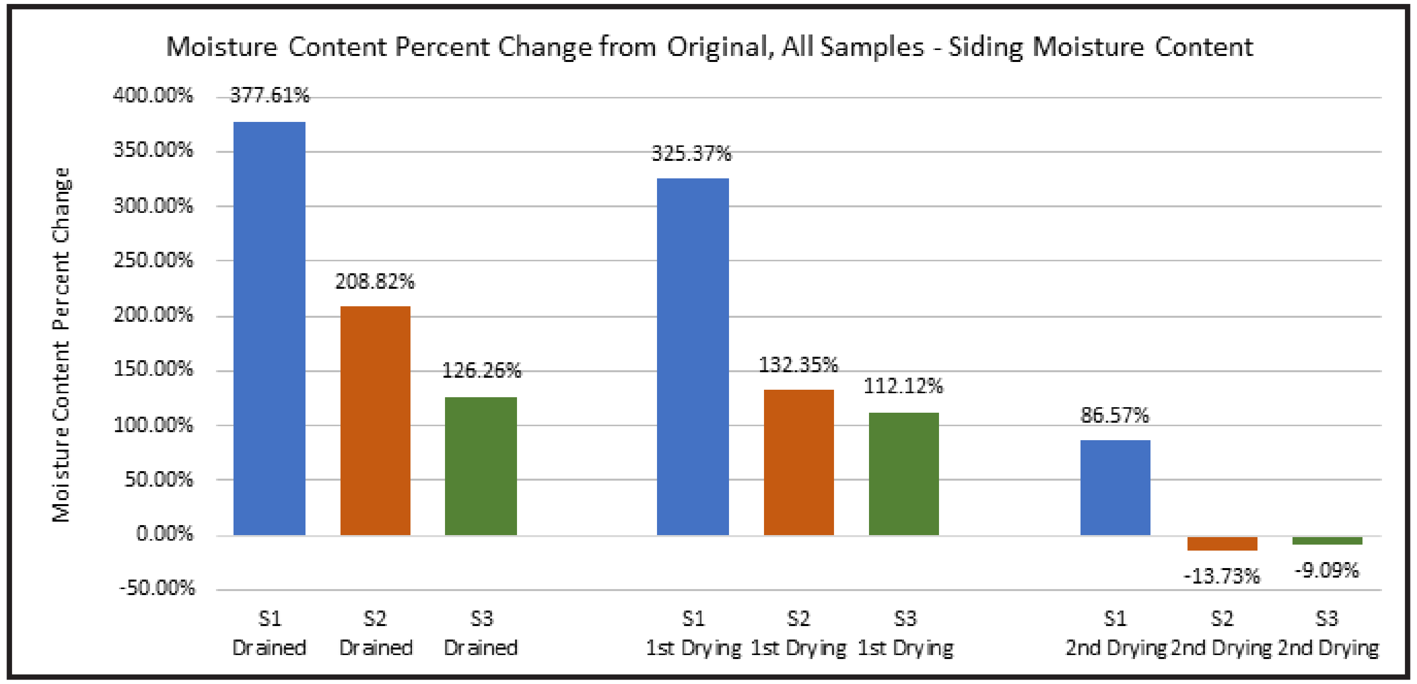
Appendix C3 Figure 13 - Sample 3 post-drying.

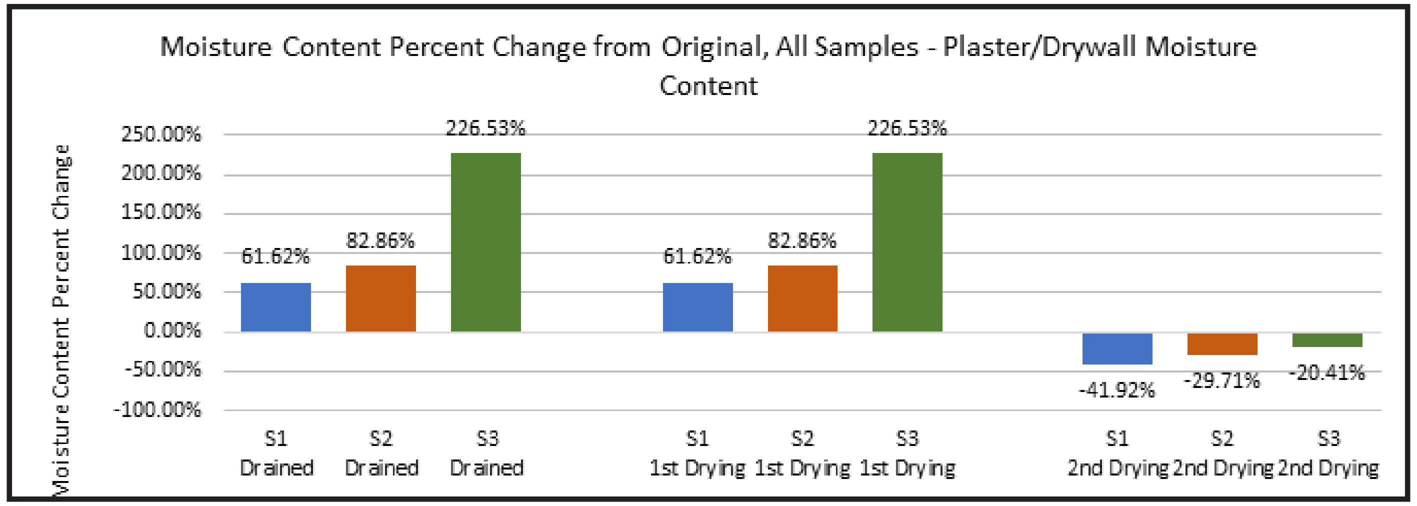
Appendix C3 Figure 14 - Sample 3 post-drying.

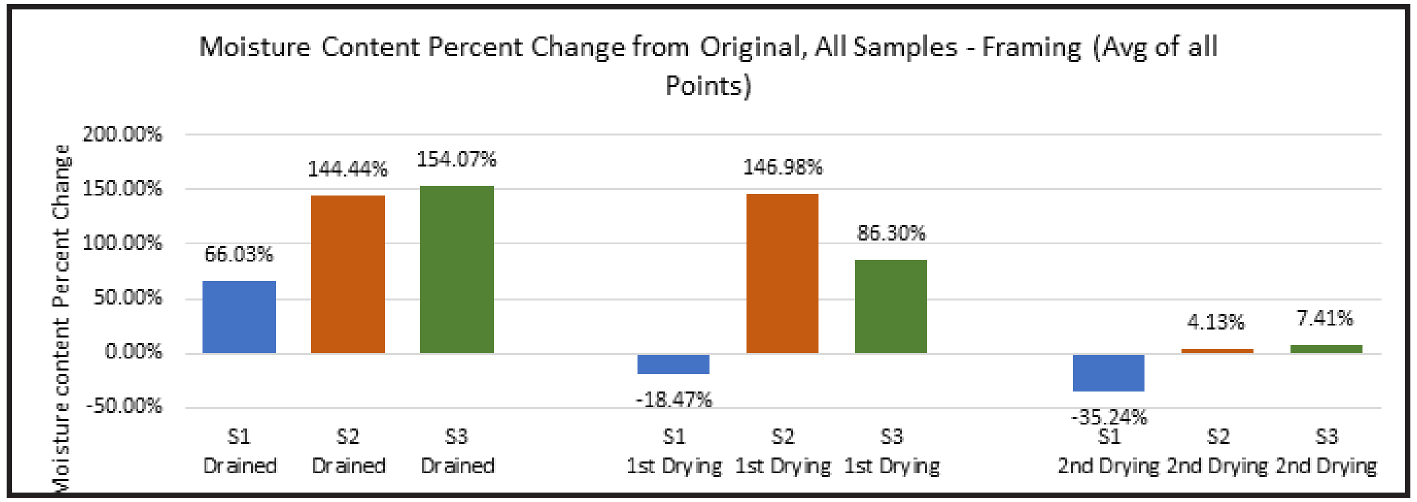


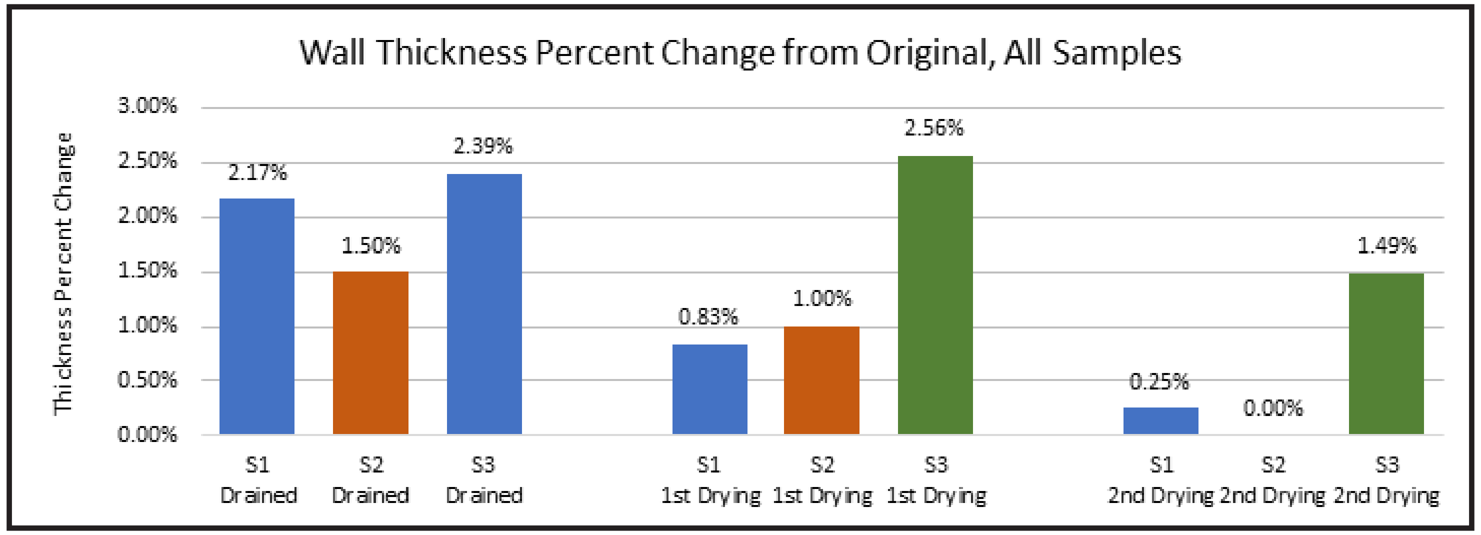
Appendix C3 Figure 15 - Sample 3 post-drying showing warped siding against a straight edge.

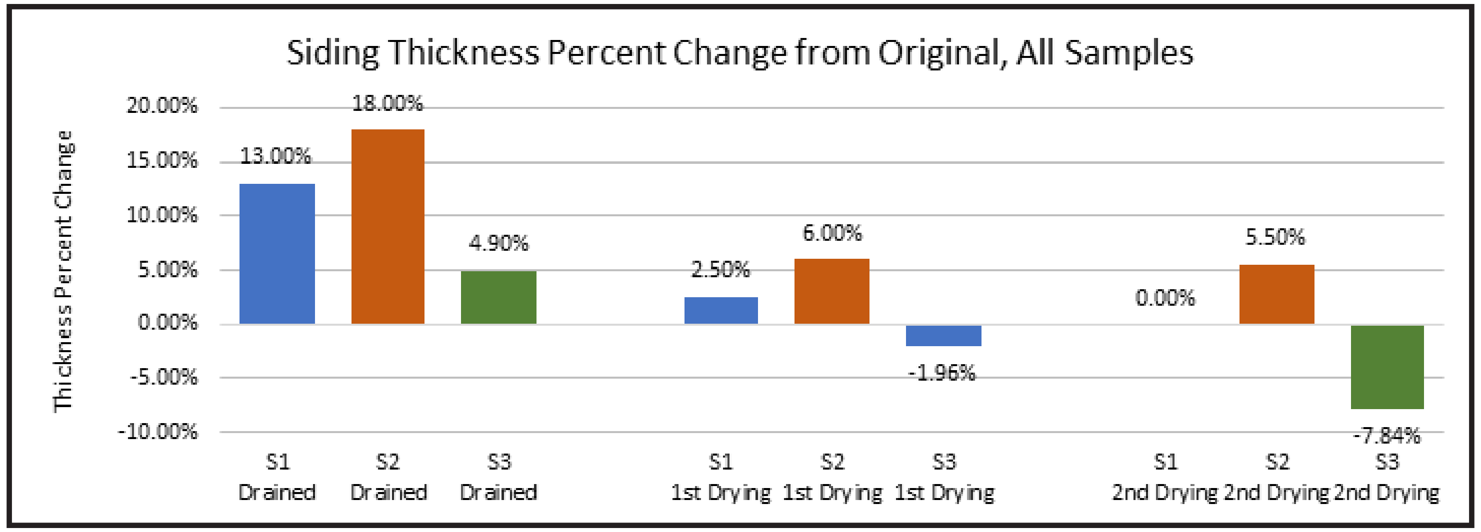
APPENDIX D: COMPARATIVE RESULTS ACROSS TESTS 1-3

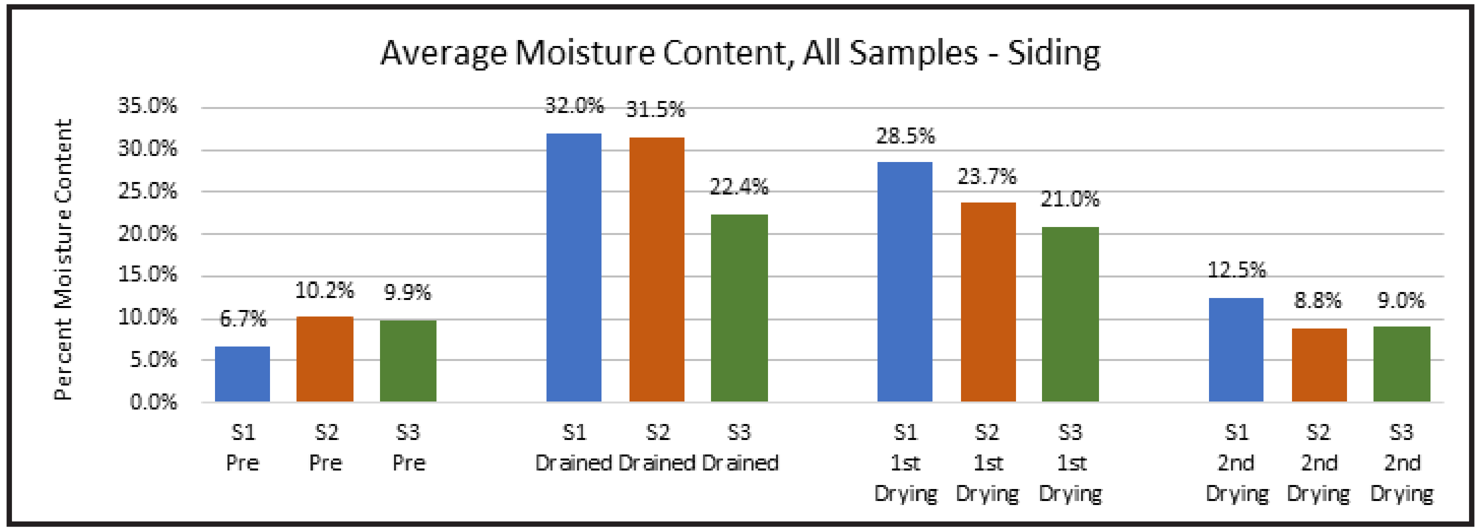


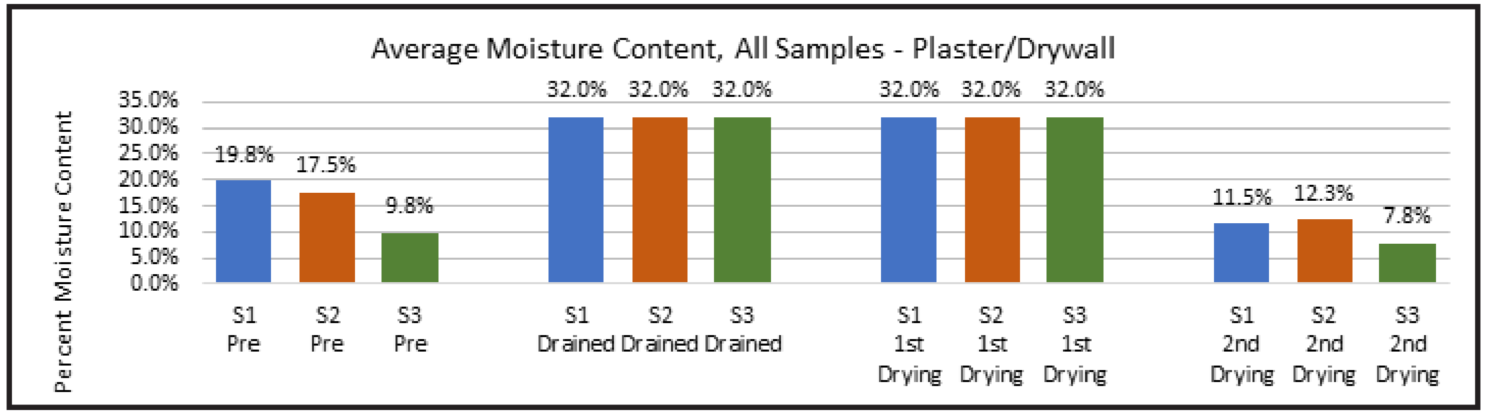


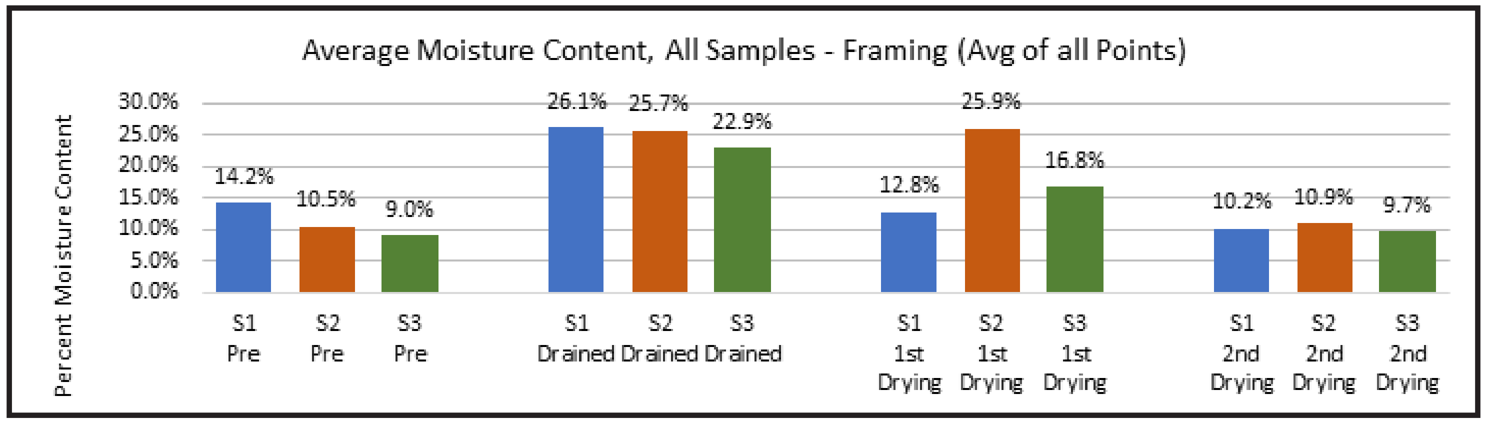


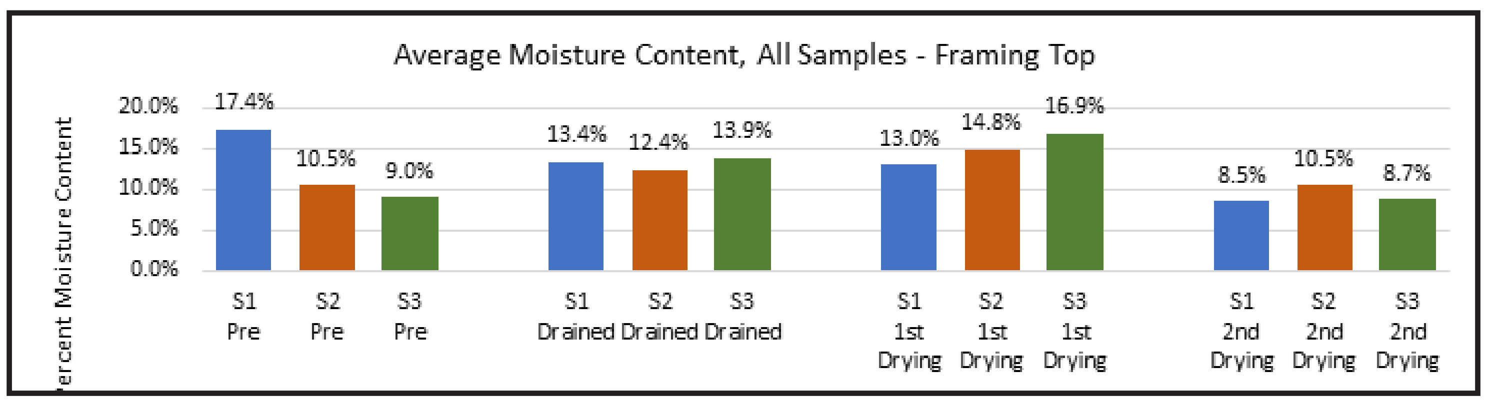


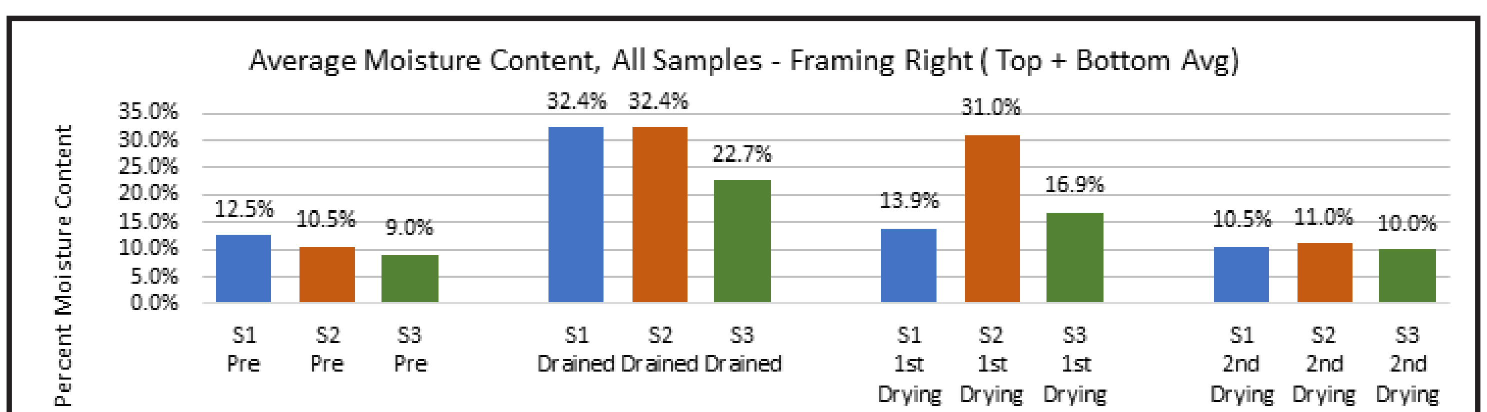


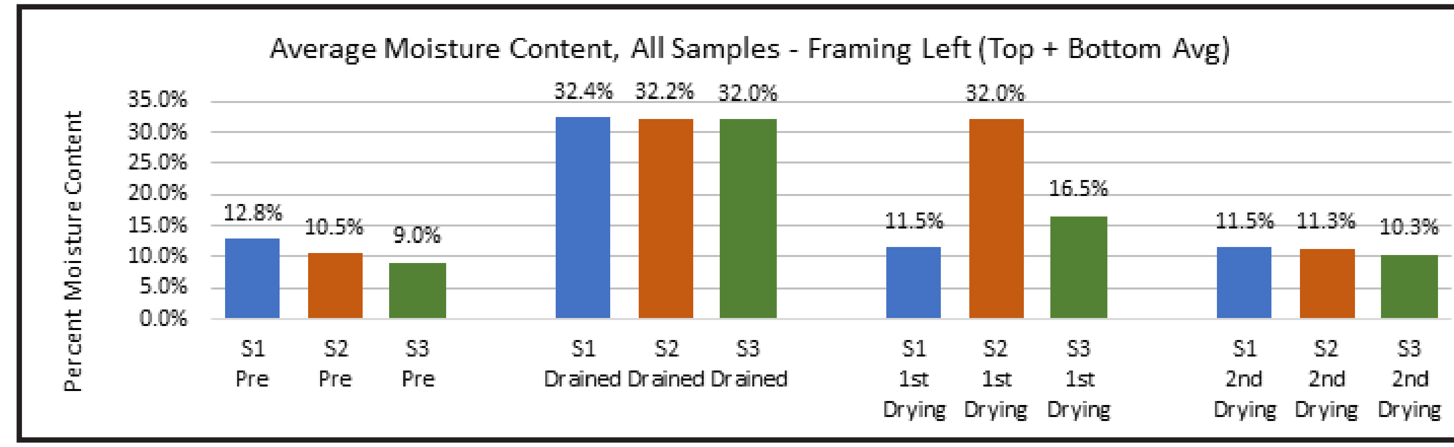


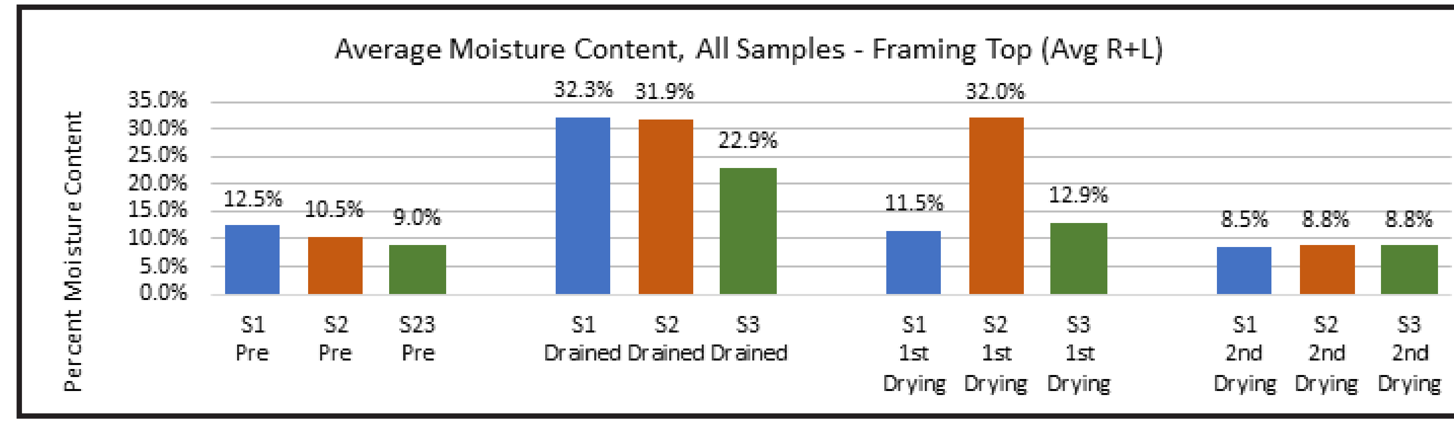

Average Moisture Content, All Samples - Plaster/Drywall
Percent Moisture Content
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
19.8%
17.5%
9.8%
32.0%
32.0%
32.0%
32.0%
32.0%
32.0%
11.5%
12.3%
7.8%
S1 Pre
S2 Pre
S3 Pre
S1 Drained
S2 Drained
S3 Drained
S1 1st Drying
S2 1st Drying
S3 1st Drying
S1 2nd Drying
S2 2nd Drying
S3 2nd Drying

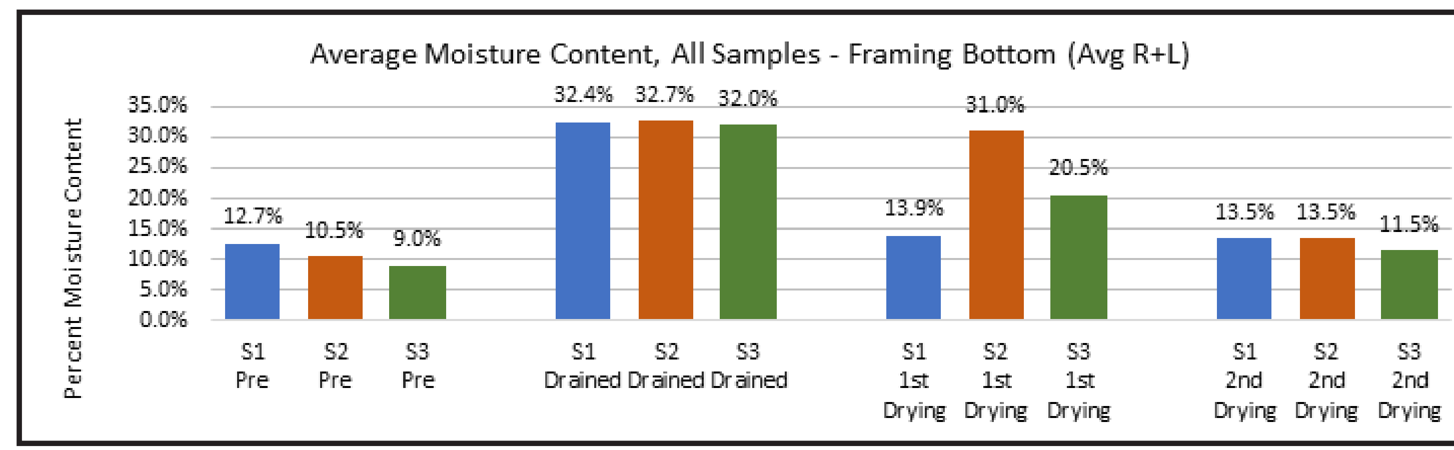

Average Moisture Content, All Samples - Framing (Avg of all Points)
Percent Moisture Content
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
14.2%
10.5%
9.0%
26.1%
25.7%
22.9%
12.8%
25.9%
16.8%
10.2%
10.9%
9.7%
S1 Pre
S2 Pre
S3 Pre
S1 Drained
S2 Drained
S3 Drained
S1 1st Drying
S2 1st Drying
S3 1st Drying
S1 2nd Drying
S2 2nd Drying
S3 2nd Drying

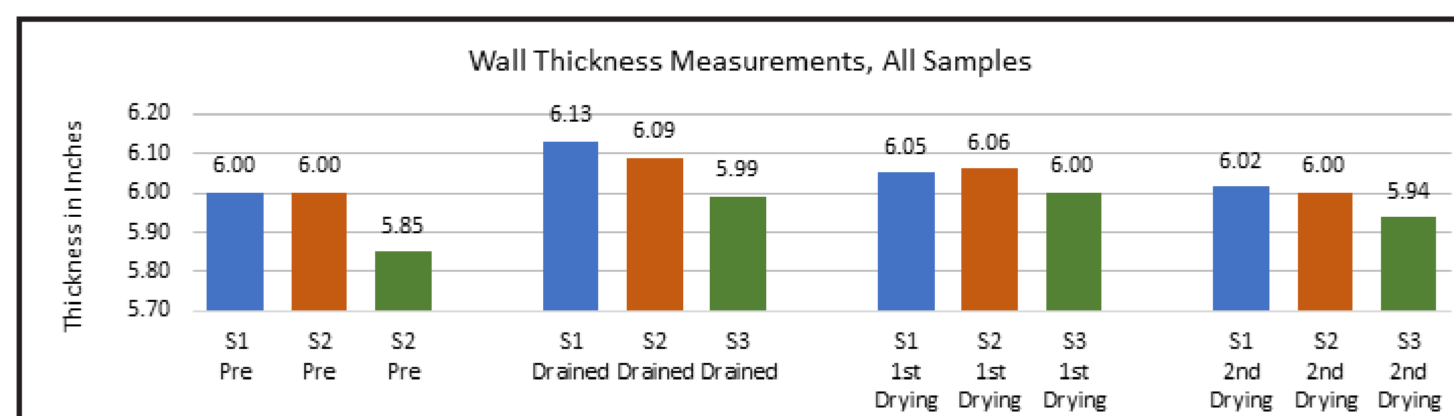

Average Moisture Content, All Samples - Framing Top
ercent Moisture Content
20.0%
15.0%
10.0%
5.0%
0.0%
17.4%
10.5%
9.0%
13.4%
12.4%
13.9%
13.0%
14.8%
16.9%
8.5%
10.5%
8.7%
S1 Pre
S2 Pre
S3 Pre
S1 Drained
S2 Drained
S3 Drained
S1 1st Drying
S2 1st Drying
S3 1st Drying
S1 2nd Drying
S2 2nd Drying
S3 2nd Drying

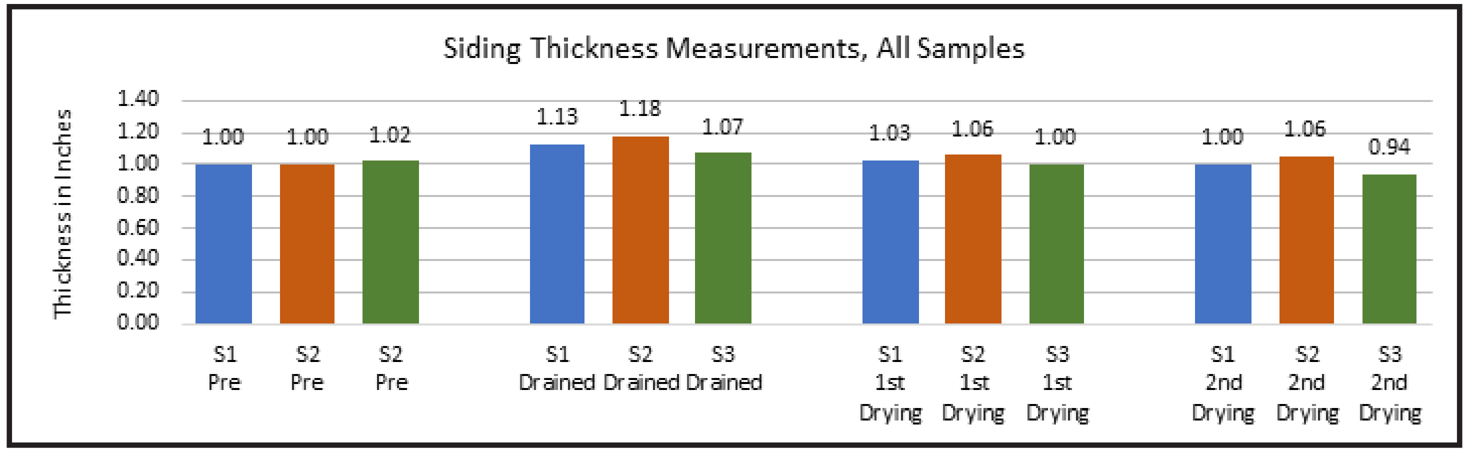

Average Moisture Content, All Samples - Framing Right (Top + Bottom Avg)
Percent Moisture Content
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
12.5%
10.5%
9.0%
32.4%
32.4%
22.7%
13.9%
31.0%
16.9%
10.5%
11.0%
10.0%
S1 Pre
S2 Pre
S3 Pre
S1 Drained
S2 Drained
S3 Drained
S1 1st Drying
S2 1st Drying
S3 1st Drying
S1 2nd Drying
S2 2nd Drying
S3 2nd Drying


Average Moisture Content, All Samples - Framing Left (Top + Bottom Avg)
Percent Moisture Content
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
12.8%
10.5%
9.0%
32.4%
32.2%
32.0%
11.5%
32.0%
16.5%
11.5%
11.3%
10.3%
S1 Pre
S2 Pre
S3 Pre
S1 Drained
S2 Drained
S3 Drained
S1 1st Drying
S2 1st Drying
S3 1st Drying
S1 2nd Drying
S2 2nd Drying
S3 2nd Drying


Average Moisture Content, All Samples - Framing Top (Avg R+L)
Percent Moisture Content
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
12.5%
10.5%
9.0%
32.3%
31.9%
22.9%
11.5%
32.0%
12.9%
8.5%
8.8%
8.8%
S1 Pre
S2 Pre
S23 Pre
S1 Drained
S2 Drained
S3 Drained
S1 1st Drying
S2 1st Drying
S3 1st Drying
S1 2nd Drying
S2 2nd Drying
S3 2nd Drying


Average Moisture Content, All Samples - Framing Bottom (Avg R+L)
Percent Moisture Content
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
12.7%
10.5%
9.0%
32.4%
32.7%
32.0%
13.9%
31.0%
20.5%
13.5%
13.5%
11.5%
S1 Pre
S2 Pre
S3 Pre
S1 Drained
S2 Drained
S3 Drained
S1 1st Drying
S2 1st Drying
S3 1st Drying
S1 2nd Drying
S2 2nd Drying
S3 2nd Drying


Wall Thickness Measurements, All Samples
Thickness in Inches
6.20
6.10
6.00
5.90
5.80
5.70
6.00
6.00
5.85
6.13
6.09
5.99
6.05
6.06
6.00
6.02
6.00
5.94
S1 Pre
S2 Pre
S2 Pre
S1 Drained
S2 Drained
S3 Drained
S1 1st Drying
S2 1st Drying
S3 1st Drying
S1 2nd Drying
S2 2nd Drying
S3 2nd Drying



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