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W. Maref[1], M.A. Lacasse[1] and D. Booth[1]

Experimental Assessment of Hygrothermal Properties of Wood-Frame Wall Assemblies — Moisture Content Calibration Curve for OSB Using Moisture Pins

ABSTRACT: As part of a research program to establish the hygrothermal response of wood-frame wall assemblies to varying climate conditions, a series of drying experiments were performed in a programmable environmental chamber used to replicate exterior climatic conditions. In these experiments, bulk moisture content of the assembly was measured using a weighing system, and as well, measurements of local moisture content of oriented strand board (OSB) sheathing were taken with the use of electrical resistance moisture pin pairs. The local moisture content of the OSB was based on the relationship between moisture content and electrical resistance determined from a series of controlled laboratory experiments on OSB specimens of the same type and thickness. This paper reports on the results from experimental tests on seven small-size OSB specimens to establish the correlation between electrical resistance and the moisture content of the OSB. The process required the installation of several moisture pin pairs at different locations on, and depths in the OSB. The weights of specimens together with resistance measurements taken across each pair of moisture pins were continuously monitored and results captured on a data acquisition unit. Details are provided in regard to electrical resistance measurements, the data acquisition unit and method of weighing specimens. The results of the tests provided a simple equation to correlate moisture content of OSB to electrical resistance measurements using moisture pins pairs and as well correlation to moisture measurements using commercially available moisture meter. Given that moisture reading results obtained from commercially available moisture meters typically correlate to a specific wood species, the work completed in these experimental tests can be used to determine moisture contents in OSB from moisture meter readings.

KEYWORDS: **calibration, drying, envelope, heat transfer, mass transfer, moisture, moisture pins, OSB, wood product**

Introduction

In respect to building envelope performance and performance assessment, the use of hygrothermal simulation models developed over the past decade have been shown to be useful in providing insights into the long-term response of different envelope components. However, acceptance of results derived from simulation models is contingent upon acquiring evidence of a response comparable to that obtained from experimental work when the simulation is carried out under the same nominal environmental loads. Hence, studies that incorporate both laboratory experimentation and simulation offer possibilities to compare results and hence 'benchmark' the response models such as hygIRC to known conditions [1].

As part of a research program to establish the hygrothermal response of wood-frame wall assemblies to varying climate conditions, a series of drying experiments were performed in a programmable environmental chamber used for replicating specific temperature and relative humidity profiles, the range of which would be consistent with those of exterior climatic conditions [2,3]. In these experiments, bulk moisture content of the entire assembly was measured using a sophisticated weighing system. As well, local moisture content measurements of oriented strand board (OSB) sheathing components were taken with electrical resistance moisture pin pairs. Retrieving the local moisture content of the OSB was based on a series of controlled laboratory experiments on OSB specimens of the same type and thickness as those used in the drying experiments.

This paper reports on the development of an electrical resistance, moisture content calibration curve and results from experimental tests on 7 small-sizes (150-mm by 150-mm) OSB specimens. The calibration process required the installation of several moisture pin pairs at different locations on, and different depths in the OSB. The weights of specimens together with resistance measurements taken across each pair of moisture pins were continuously monitored and results captured on a data acquisition unit (DAU). The calibration curve permitted determining local moisture content values in the OSB component at specific locations from which the moisture content distribution in the OSB could then be determined. Details are provided in regard to the electrical resistance measurements, data acquisition unit and method of weighing specimens. As well, examples are given on the use of the calibration curve to extract moisture content data from experiments on mid- and full-scale experiments.

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Procedure for calibrating Moisture Pins Sensors for OSB

Overview and Approach

The procedure for determining the moisture content in OSB specimens calibrated to readings taken from electrical resistance measurements using moisture pin gauges essentially consisted of saturating a series of specimens of known size and weight and thereafter slowly drying these such that moisture contents based on weight changes could be correlated to corresponding measurements using moisture content (resistance) gauges. Given the requirements of the overall experimental program related to benchmarking mid-scale (0.8-m by 1-m) and full-scale (2.44-m by 2.44m) test specimens, and the need for a data acquisition unit (DAU) to acquire calibrated electrical resistance measurements to continuously monitor changes in moisture content of the various specimens (see, e.e.,[1]), the procedure was completed in a two step process that involved: (i) Verifying the moisture content readings obtained using a Delmhorst moisture meter to that of small (150-mm by 150-mm) OSB specimens of known degree of saturation determined by weight measurements; (ii) Calibrating the DAU to measurements using the Delmhorst moisture meter in a drying experiment in which the transient moisture content of saturated OSB specimens was monitored over time. A summary of the approach is illustrated schematically in Figure 1.

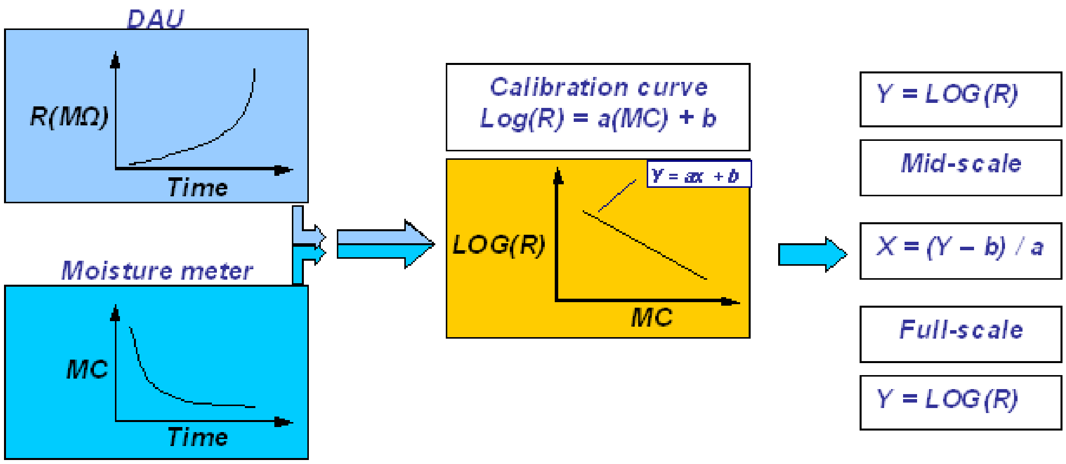

FIG. 1—Schematic illustrating the approach taken in calibrating the DAU to the Delmhorst moisture meter to derive a calibration curve; moisture contents of OSB panels used in subsequent mid- and full-scale experiment tests were based on the calibration curve and electrical resistance measurements acquired on the DAU.

Equipment

A description of the equipment to carry out the benchmarking trials is provided that includes information on the data acquisition and control system and Delmhorst moisture meter.

Data Acquisition System

The data acquisition unit (DAU) was configured with a software control and acquisition program used to collect data from moisture pin sensors. This permitted logging electrical resistance data from various different tests simultaneously including 32 moisture pins pairs allocated for calibration of the moisture content of OSB specimens. The data acquisition and control system consisted of three basic hardware modules: a command module, a data multiplexer and a digital multimeter (HP-E1476A). The command module transfers software instructions from a local computer to the automated data logging multiplexer to collect and measure data on the digital multimeter. Readings were taken every 10 seconds and directly downloaded to the hard drive where access to the data could be made on a continual basis.

Delmhorst Moisture Meter

A wood moisture meter (Delmhorst; model J-2000) was used to obtain resistance and related moisture content values of wood specimens. The temperature compensated device measures moisture content over a range of 6% to 40% (±0.2%).

Specimen Preparation

A series of 7 OSB wood specimens of nominal size 11.5-mm by 150-mm by 150-mm were cut from a standard sheet of 1220-mm by 2440-mm OSB. Note was taken of the orientation of strands on the surfaces of the specimens such that moisture pins could subsequently be oriented in the direction of the strands, as required for the test procedure. The initial thickness of each specimen was then measured at its four extremities, 12-mm from the outside edges, to the nearest 0.001-mm using precision calipers. Pairs of insulated moisture pins of 28-mm length were then inserted into pre-drilled holes spaced ca. 25-mm apart (Figure 2). The holes were bored to varying depths with moisture pins inserted to ½, and ¾ specimen depths. Each pair of pins was located on the specimen such that the line between pin pairs was parallel to the principal strand (wafers) orientation in the layer to which they were subsequently inserted. The values for initial weights of individual specimens, their respective measured dimensions (to the nearest 0.01-mm) and calculated volume and density are given in Table 1.

FIG. 2—Moisture pins inserted in OSB sample

Spec.	Initial Weight (g)		Thickness (mm)										Length	Width	Vol (m³)	Density (kg/m³)
	Without pins	With pins	1	2	3	4	5	6	7	8	9	Avg.				
1	178.65	186.36	11.54	11.63	11.70	11.49	11.66	11.46	11.51	11.60	11.50	11.57	150.63	150.60	0.0002624	680.926
6	155.87	163.36	11.66	11.69	11.64	11.56	11.62	11.63	11.57	11.65	11.69	11.63	150.07	150.43	0.0002627	593.456
7	159.56	167.08	11.52	11.61	11.64	11.62	11.62	11.69	11.52	11.63	11.70	11.62	149.92	150.60	0.0002623	608.356
10	171.76	179.27	11.67	11.79	11.71	11.78	11.77	11.73	11.81	11.78	11.81	11.76	150.34	150.53	0.0002662	645.321
12	166.18	171.66	11.71	11.69	11.70	11.70	11.73	11.66	11.67	11.72	11.61	11.71	150.29	150.52	0.0002649	627.332
14	177.26	182.70	11.69	11.66	11.75	11.62	11.69	11.64	11.69	11.70	11.78	11.69	150.41	150.63	0.0002649	669.217
15	174.75	180.25	11.71	11.70	11.69	11.63	11.72	11.61	11.67	11.75	11.69	11.69	150.50	150.47	0.0002646	660.361

TABLE 1—Weights and dimensions of OSB specimens used in the calibration of moisture pin gauges

Calibration Procedure

The specimens were weighed and the laboratory conditions recorded (i.e. temperature and relative humidity) such that the moisture content could subsequently be determined. (Note that this weight is not necessarily the equilibrium MC of the material at these conditions). The specimens were then immersed in water to achieve saturation insuring that all free surfaces were completely immersed (Figure 3). An initial three-day immersion period was used following which confirmation that saturation has been attained was determined by monitoring the weight change of several specimens at 4-hour intervals over the fourth day.

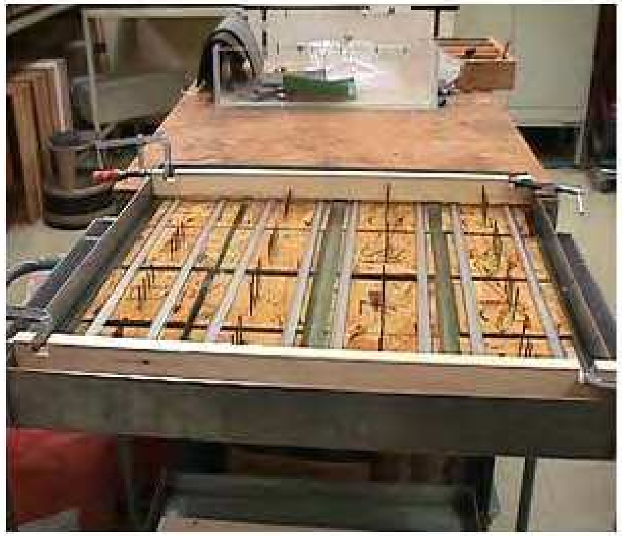

FIG. 3—Pre-conditioning of OSB Samples

Moisture measurements were taken on all specimens (Figure 4 and Figure 5) and the differences between core moisture readings and those at other depths were examined to determine evidence of any significant moisture gradient; this permitted verifying if the specimens had nominally achieved an uniform moisture content. Under conditions of uniform moisture content, specimen weights were recorded, as were moisture content values determined from the Delmhorst wood moisture meter or electrical resistance across moisture pin pairs to the DAU.

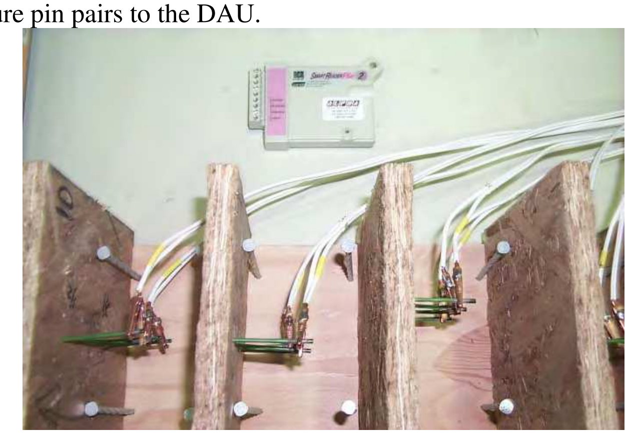

FIG. 4—Top view of the calibration set-up

FIG. 5—Calibration of the moisture pins on OSB

Verification of Delmhorst Readings to Bulk Moisture Content of Small OSB Specimens

The results obtained for the transient loss in bulk moisture content of small OSB specimens by weight measurements as compared to that provided by the Delmhorst moisture meter readings are given in Figure 6. Readings were taken on a regular basis on weekdays, twice a day at approximately the same time, for a period of ca. 22 days. The transient moisture content over the time for each of 7 OSB specimens is given in terms of moisture content determined by weight measurements (MC_{WT}) and moisture content obtained from Delmhorst meter readings (MC_{DH}). Exponential equations were fitted to the respective data sets; the information provided from the regression indicates that the shape of the drying curves are similar as are the respective equation parameters; the correlation of data, as indicated by the value of the correlation coefficient, in both instances suggests adequate degree of correlation of the data sets to these functions.

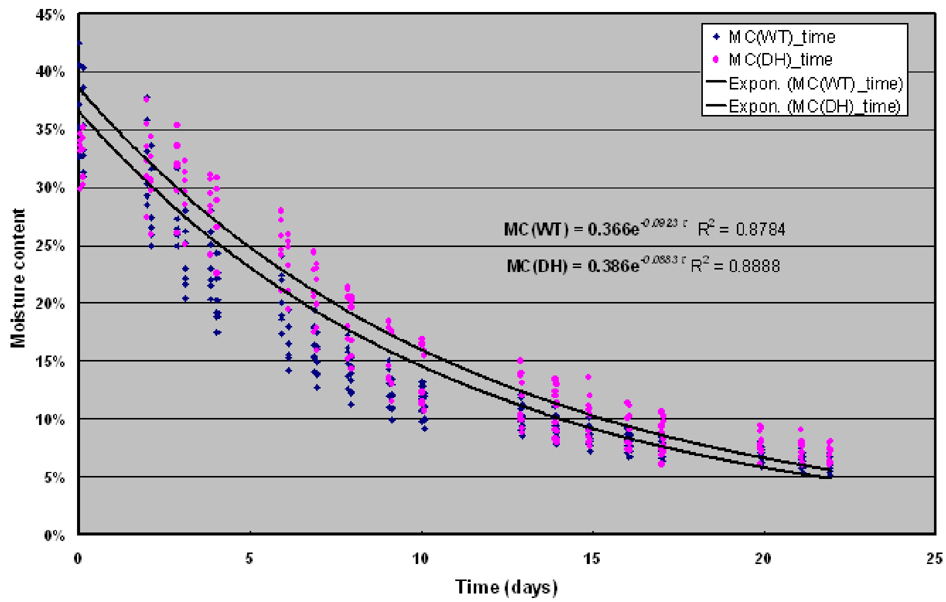

FIG. 6—Transient moisture content of OSB specimens derived from Delmhorst meter readings and by weight measurements

The values for moisture content derived from either of these two functions are compared in Figure 7. The information provided in this Figure indicates that the values of the function for the Delmhorst moisture meter are all greater than those of the function derived by weighing but the difference throughout the entire range of values (i.e. ca. 6 to 39% MC), is less than 10%.

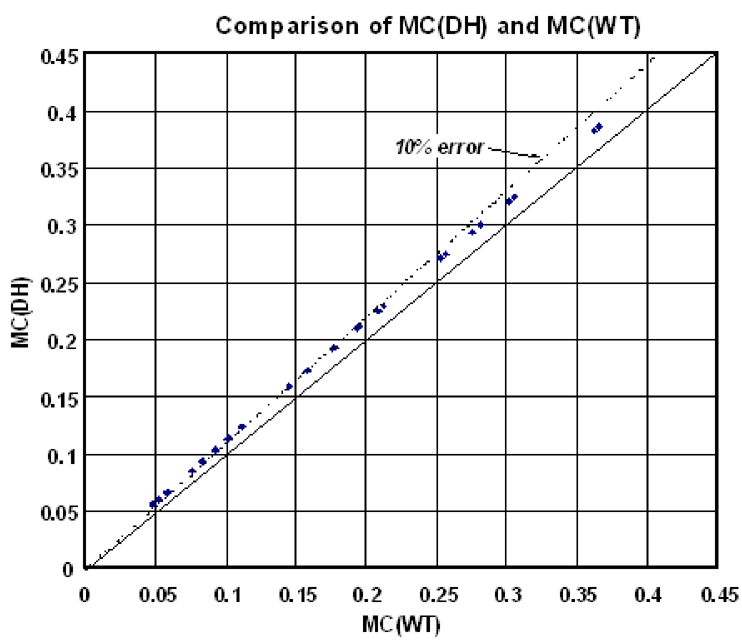

FIG. 7—Comparison of moisture content functions derived for Delmhorst meter (MC_{DH}) and by weight (MC_{WT})

This suggests that the Delmhorst meter function approximately provides MC values that are at most, 2 percentage points greater than the function derived by weighing. On average, MC values obtained from the Delmhorst mc function were 1.4 percentage points greater than that determined by the weighing function.

The relation between the moisture content function derived from weight measurements (MC_{WT}) and that from the Delmhorst meter (MC_{DH}) is given by eq 1.

$$MC_{WT} = e^{1.055 \ln MC_{DH} + 0.001187} \quad (1)$$

Hence, when using a Delmhorst meter to determine the local moisture content in an OSB panel, moisture meter readings are corrected using eq 1.

Calibration of DAU to Delmhorst Moisture Meter Readings

In a subsequent experiment to calibrate the DAU, saturated OSB specimens were dried out over a 10-day period and changes in moisture content were observed from readings of the Delmhorst moisture meter and that of electrical resistance measurements acquired with the digital multimeter component of the DAU.

The results from readings of moisture content of the OSB specimens using the Delmhorst moisture meter are provided in Figure 8 and that of the DAU in Figure 9. The calibration curve that relates the logarithm of the electrical resistance (in Ohms) to that of the Delmhorst moisture meter is given in Figure 10. The moisture content (MC) was obtained using eq 2 which was derived from the calibration curve provided in Figure 10:

$$MC (\%) = 100 \times [\text{Log (Resistance } (\Omega)) - 9.1884] / (-14.152) \quad (2)$$

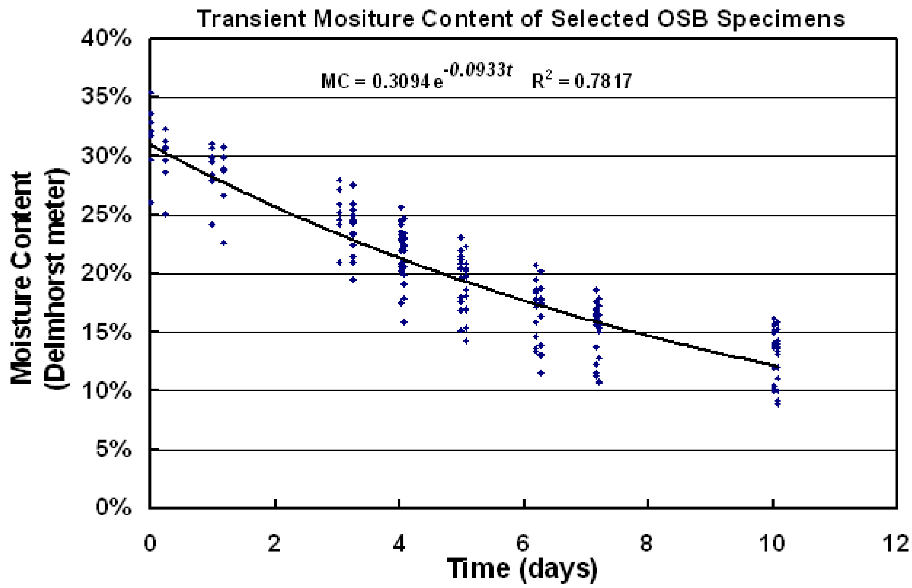

FIG. 8—Transient moisture content of OSB specimens as determined from Delmhorst moisture meter measurements

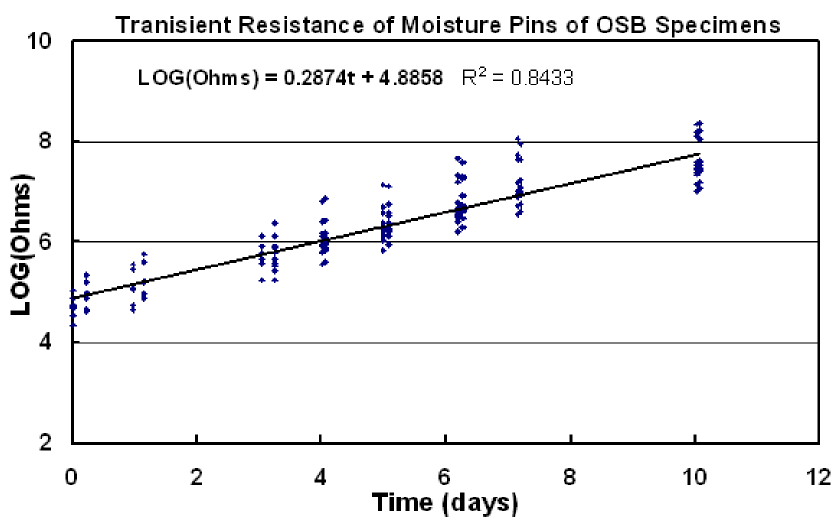

FIG. 9—Transient moisture content of OSB specimens as determined from electrical resistance measurements of the DAU

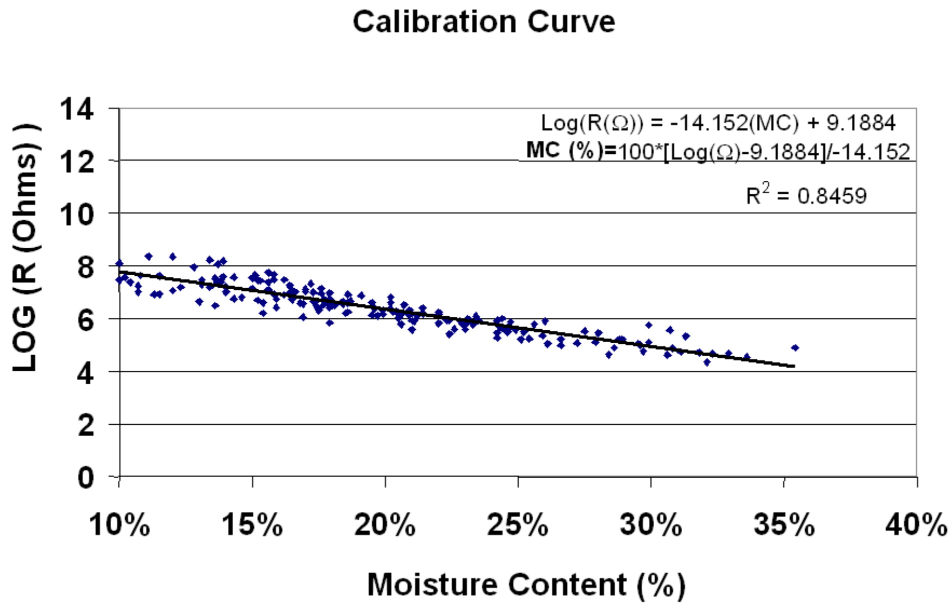

FIG. 10—Transient moisture content of OSB specimens as determined from electrical resistance measurements of the DAU

As expected in a drying experiment, the moisture content decreases over time and the corresponding electrical resistance measurements increase significantly over the course of the experiment. Accordingly, as shown in Figure 8, values for moisture content as measured with the Delmhorst moisture meter decease from and initial value of approximately 34% to ca. 11% over the 10-day drying period. Likewise, there is a corresponding increase in the electrical resistance as measured by the DAU exceeding 120 MΩ in this same period

The calibration curve provided in Figure 10 was that used to estimate the moisture content at local points on OSB panels used in mid- and full-scale experiments. To illustrate the usefulness of this calibration curve, some of the results from these experimental sets are briefly summarized in the subsequent sections.

Transient Moisture Transfer of OSB Panels from Mid- and Full-Scale Experiments as Derived from Calibrated Moisture Sensors

Two experiments we carried out using the calibrated moisture pins both of which were transient experiments that involved the wetting and drying of OSB panels to verify the drying rate of these building components and provide data to benchmark a hygrothermal simulation model. The first of these experiments, referred to as mid-scale experiments, and also described by Maref et al. in [4] [5] [6], [7], focused on the drying of saturated OSB panels (0.8-m by 1-m) that had, or had not been wrapped in different types of sheathing membrane. The second was a similar transient experimental set that was conduced on full-scale specimens (2.44-m by 2.44-m) [8], [9]; brief summaries of selected results of both of these experiments are provided to illustrate the usefulness of the moisture sensors. Detailed results for each of these studies can be found in the references provided.

Selected Results from Mid-Scale Benchmarking Experiments [1]

Selected results from mid-scale (0.8-m by 1-m) experimental tests conducted to benchmark the response of the wall assembly to that of the hygrothermal simulation model, are presented; additional details on these studies can be found in [1] and related references.

In these experiments, OSB panels, some wrapped with protective membranes of the type typically used in construction, were subjected to controlled environmental conditions in a climatic chamber over a 30-day period. Their weights were monitored continuously, as were the temperature and relative humidity in the chamber. As well, the panels were fitted with sets of moisture pin pairs to determine the local moisture content in the panels over the course of the drying experiments.

Figure 11 shows the change in moisture content in relation to time (days) in an OSB panel specimen ([1]; Specimen 5) for 6 moisture pin (MP) pairs. The bottom portion of the OSB panel (M14) starts drying at a significant rate (change from 27% to 10% MC) after the second day of the experiment, whereas at the uppermost part (M10), a similar rapid drying rate only occurs after 7 days. Hence the upper part of the is clearly remains wet longer than the lower part as rates of drying for locations M10, M11, and M12 are all slower to initiate as compared to the lower locations at M9 and M14. After 12 days, asymptotic values of moisture content are observed at all MP locations, attaining a value of ca. 6% MC. As is shown in this Figure, the bottom part of the specimen dries faster; this was thought to be due to air movement in the environmental chamber in which the experiments were conducted, that preferentially the tops of specimens were exposed as compared to the lower parts.

Based on these data it can be stated that, in general, the rapid drying rate observed was adequately described by the response obtained from the moisture pins and the drying process can thus be reasonably well ascertained based on these types of measurements.

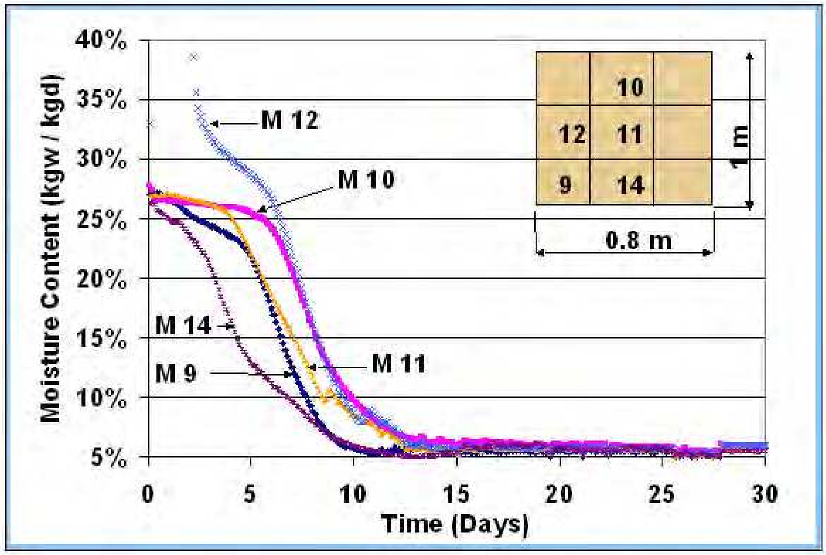

FIG. 11—Local moisture content of mid-scale OSB panel ([1]; Spec. No. 5)

Figure 12 represents the moisture content in relation to time of an OSB wrapped in a "15-lb. felt" membrane in which were placed 6 moisture pin (MP) pairs located as shown in the inset figure; M27 located at the uppermost part of the panel, M28 and M29 installed at mid-height of the panel, and a final three (3) pairs, M30, M31, M32, located at the lowermost portion of the panel.

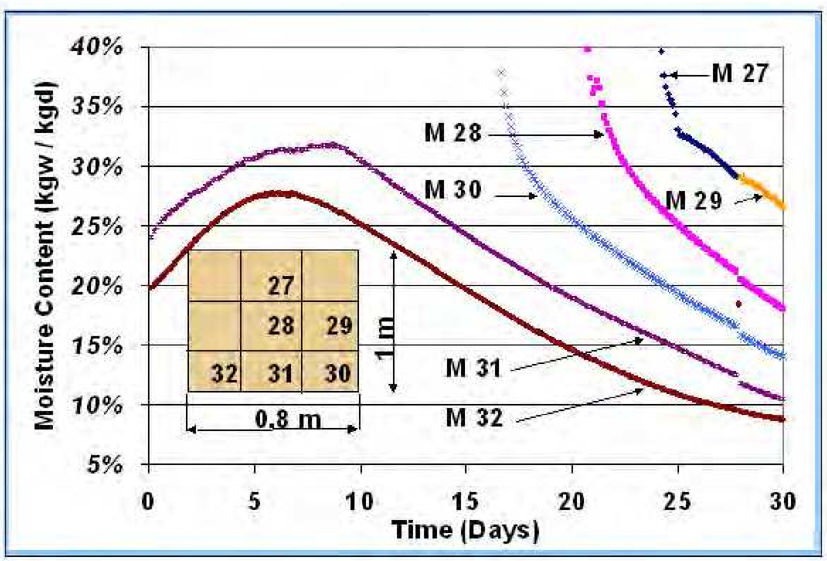

FIG. 12—Local moisture content of OSB panel wrapped with "15 lb. felt" membrane ([1]; Spec. No. 9; membrane V)

After 30 days of experiment, not all MPs indicated lower moisture content; hence, it is evident that the OSB sheathing panel did not completely dry. For example, it can be observed at the uppermost portion of the panel moisture pins M27, M28, M29 still indicated relatively high moisture contents in excess of 60%, that also corresponded to very low resistance readings. Of interest in these experiments were the range of MC readings in OSB that would indicate a very dry or fully saturated panel that is, between a MC of 6% and 30%. The low vapor permeability of the felt membrane controls the drying rate of the panel as compared to that given for OSB alone (Figure 11).

The information provided in this figure also shows that the lower portions are significantly drier than the upper parts; M31 and M32 have lower MC than that of pin locations above it. As well, there appears to be a redistribution of moisture after five days to the lower MP locations as shown by the increasing MC of M31 and M32 at ca. 5 days. Thereafter, the drying rate for both these locations increases.

The response of the OSB panel wrapped in membrane is in contrast to that of the OSB panel alone; the information provided by the moisture pin sensors offered additional details in respect to the mode of drying, the local drying rates and the relative, and significantly, quantifiable difference in response of the different locations on the specimens to controlled environmental conditions.

Selected Results from Full-Scale Experiments

Selected results from full-scale experimental tests conducted to benchmark the response of the wall assembly to that of the hygrothermal simulation model, are presented; additional details on these studies can be found in [1] and related references. Full-scale wall assemblies consisted of two OSB panels having nominal dimensions of 2.44-m by 1.22-m, installed on a 2.44-m by 2.44-m wood-frame, with the longer panel dimension being placed horizontally across the frame. Figure 13 shows the overall configuration of the wall specimen, the location of each moisture pin (MP) sensor, and the set of MP sensors that comprise each of six zones. Each zone is representative of the size of specimen used in the mid-scale tests (i.e. 0.8-m by 1-m). The moisture content (MC) data retrieved from each zone provides the basic information needed to map the MC distribution all over the entire wall. For the purposes of illustrating the use of the data acquired from the resistance measurements across the moisture pins, only information on Zone1 is presented here.

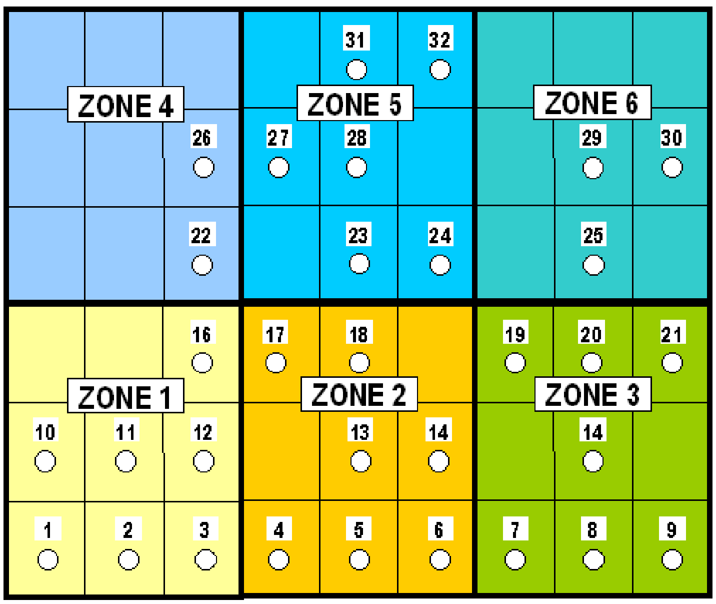

FIG. 13—Moisture pin locations

Figure 14 shows the results derived from drying the OSB panel in Zone 1 in which the change in resistance (MΩ) in relation to time (days) of the OSB for each 7 moisture pin (MP) pairs is given. The drying process appears to be very rapid; after 10 days the resistance values across moisture pin sensors lies between 80 MΩ and 700 MΩ for all specimens. In another words, the MC in this zone is between 12.7 % and 10 % MC. Thereafter, the rate of change resistance values for all pin pars tends to diminish at15 days and after 20 days the resistance values range between 500 and 650 MΩ; the lack of change in resistance values indicates that the OSB is tending to reach the equilibrium moisture content with its surroundings, estimated at 5% MC or ca. 750 MΩ.

In this figure, the change in resistance of MP16, located at the uppermost portion of Zone 1, is first observed at ca. 5 days whereas the same demarcation only occurs after ca. 10 days for MP1, which is located at the bottom of the panel. MP1 also has the lowest rate of change in resistance over time and retains the lowest resistance value at the end of the drying experiment. The contrasting response between these two moisture pin locations is clearly indicative of the relative degree of wetness at these locations and hence provides useful information on the possible accumulation of moisture at the base of wetted panels and the gradient between panel extremities.

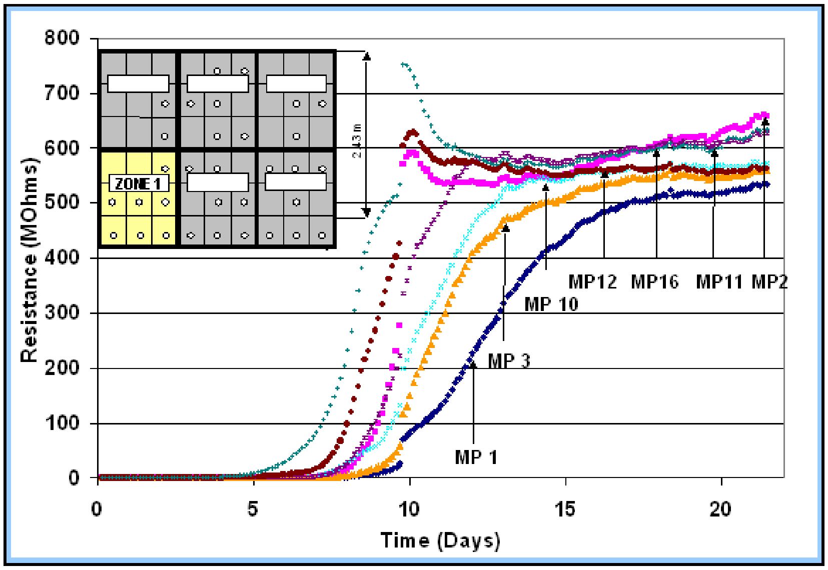

FIG. 14—Resistance (MΩ) versus time of 7 moisture pin pairs in Zone 1 of full-scale specimen

Based on the resistance measurements given in Figure 14, the MC of the different locations is shown in Figure 15. This information indicates the corresponding response in terms of MC based on the MC calibration curve and shows the drying response for the OSB panel in Zone 1 in terms of change in MC over the course of the 22-day experiment. The drying rate of any MP location is given by the change in moisture content as a function of time (i.e. slope of the $\delta MC/\delta t$ function).

It is apparent from the early rate of change in moisture content of MC16, located at the top of Zone 1, that this MP location is first to indicate drying in contrast with those pin pairs located at the bottom (i.e. MC1, MC2, MC3). The drying rates of these locations at the bottom of the panel do not increase until ca. day 6.The response of MC12 is similar to MC16, located just above it; although the drying process is not initiated until perhaps day 4. The rate of drying for MC12 is greater than that of MC16, though the drying response after day 10 is quite similar to that of MC16. The MC at the end of the experiment (i.e. ca. day 22) is similar for both these MP locations. Likewise MC10 and MC 12 have a similar response in terms of initiation of the drying process, maximum drying rate, and time to reach the equilibrium condition at the end of the experiment.

Once the drying process is initiated, the rates of drying are approximately the same for all MP locations with the differences noted above. The difference in respect to moisture content among the different MP locations appears to be how soon the process is initiated and thereafter, how quickly it tends towards equilibrium conditions at ca. 4.5% MC. The results indicate that the bottom has a tendency to stay wet while the top dries out. Evidence of this can be more clearly observed from the resistance measurements (Figure 13) that show after the experiment was complete, the residual resistance for MP16 is greater (lower MC) than that of MP 1 (i.e. 630 MΩ) vs. 525 MΩ) located at the bottom.

These results serve to highlight the differences in response to changes in moisture content as related to the different locations on the panel; higher up on the panel, a greater rate of drying is evident whereas lower rates of drying tend to occur at lower panel locations. The relative importance of drying rate and MC of the different locations can readily be appreciated.

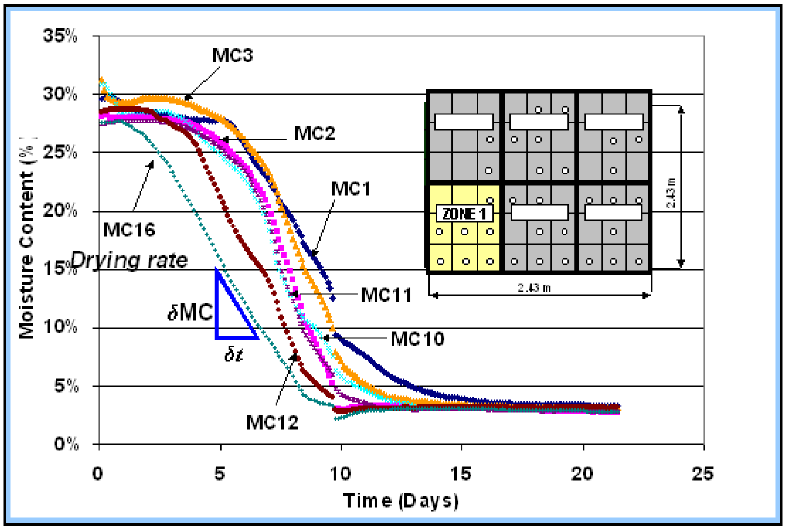

FIG. 15—Moisture content versus time of the 7 moisture pins in Zone 1

Conclusions

Experimental work was carried out to establish the relationship between the bulk moisture content of small-scale OSB specimens and Delmhorst wood moisture meter readings. These in turn were used to determine a calibration curve between the Delmhorst readings and electrical resistance measurements acquired on a data acquisition unit (DAU).

The following calibration curve was used to obtain local moisture content values for mid-scale and full-scale specimens thus providing quantitative information on the moisture content of the OSB in each zone over the time the drying experiment was conducted with resistance readings using moisture pins sensors.

$$\mathbf{MC\ (\%) = 100\ X\ [Log\ (Resistance\ (\Omega))\text{-}9.1884]\ /\ (\text{-}14.152)}$$

In general, if a Delmhorst meter is used in an experiment, the reading should be corrected with the following equation:

$$MC_{WT} = e^{1.055\ ln\ MC_{DH} + 0.001187}$$

The calibration curve was used to obtain local moisture content values for mid-scale and full-scale specimens thus providing quantitative information on the moisture content of the OSB in each zone over the time the drying experiment is conducted.

Acknowledgement

Thanks are extended to Mr. Daniel Perrier for setting-up and undertaking the experiments and Mr. Raymond Demers and Yvon Tardiff for the preparation of the moisture sensors. Thanks are extended to Mr. Don Onysko from DMO for his precious guidance.

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