

Effect of a Water Repellent on Moisture Intrusion Patterns in Small-Scale Mass Ply Panel Floors

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Abstract

Mass timber has gained increased global interest as builders seek more carbon neutral materials. These products are primarily intended for interior uses where the wetting risk is minimal. One relatively new mass timber material is mass ply panel (MPP), which uses multiple layers of orthogonally placed veneers in different patterns to create thicker wall and floor panels. Moisture intrusion is worth considering in these materials because it can have many detrimental effects on engineered wood products, including swelling, cracking, delamination, and, if prolonged, fungal decay. These products are manufactured using wood that is well below the fiber saturation point (generally <27% to 30%), but wetting can occur between manufacturing and final building closure. Understanding rates and degree of moisture intrusion can guide moisture-management strategies to mitigate risk of wetting and ensure performance. Water uptake was assessed in Douglas fir MPPs with and without a topically applied water repellent. Moisture contents in noncoated panels exceeded 40 percent in the upper four plies after 1 day of wetting but increased more slowly further inward. Moisture contents also increased in the first few veneers in water repellent-treated panels but at a much slower rate. Prolonged wetting (24 days) of nontreated panels resulted in moisture levels above 20 percent deeper in the panel. The results highlight the speed with which MPP sorbs water near the surface and can be used to develop mitigation methods to minimize wetting risks. They also show that water repellents slow, but do not completely inhibit, water ingress.

Timber has gained increased interest due to its positive environmental attributes including low embodied energy, recyclability and ability to sequester carbon (Duan et al. 2022). A major driver of this interest has been the emergence of larger engineered wood products, termed mass timber. Mass timber is not a new concept; laminated timbers have been used for more than a century, but the emergence of cross-laminated timber and, more recently, veneer-based mass timber has sparked considerable interest in the engineering and architectural communities. Although the public focus has been on visible high-rise structures, there is considerable opportunity for mass timber in low- and midrise structures (Karacabeyli and Douglas 2013).

In most instances, mass timber elements are intended for interior applications where minimal risk of wetting, which might lead to biodeterioration, is found (Wang et al. 2018, Singh et al. 2019, American Wood Council 2024). These products are produced at moisture levels well below 20 percent moisture content and thus present minimal risk of biodeterioration once installed. However, there is a considerable risk of moisture intrusion in mass timber elements between manufacturing and building envelope completion. Moisture can be introduced via tears in the barriers used to wrap panels or via rainfall before the building is enclosed. Prolonged moisture accumulation will invariably support the development of fungal decay that

will sharply reduce the material properties of the timber (Cappellazzi et al. 2020; Udele et al. 2021, 2023).

There are an increasing number of reports of decay in mass timber buildings either through poor detailing or failure to control

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wetting during construction (Wang and Thomas 2016, Morrell et al. 2018, Schmidt and Riggio 2019, Shirmohammadi et al. 2021, Austigard and Mattsson 2020, Olsson 2021, Lima et al. 2024). Moisture intrusion can lead to wood swelling, delamination along the glue lines, and, if prolonged, fungal decay. Unlike traditional stick-frame buildings where the frame can be subjected to rapid drying to remove any moisture that accumulated during construction, mass timber elements are much more sensitive to rapid drying and can experience cracking, delamination, and other physical degradation as the wood equilibrates to an in-service moisture level (Naim 2019).

Understanding the rates and degree of moisture intrusion during construction can help encourage moisture exclusion measures. Many manufacturers already minimize wetting risk by wrapping panels in plastic to exclude water and using just-in-time delivery to minimize storage on site. However, water intrusion can still occur between installation and completion of building enclosure. Some builders have worked to minimize wetting by capping walls with plastic to minimize end-grain exposure to rainfall, taping floor joints, and applying water repellent coatings. However, moisture can still accumulate on floors, especially during periods of heavy rainfall. Understanding

the extent of moisture intrusion and the potential effects of water repellents can help guide both the extent to which moisture exclusion procedures are undertaken as well as the amount of postconstruction drying needed.

Previous studies used mass gain and computed tomography (CT) scans to examine moisture accumulation and distribution in Douglas fir cross-laminated timber (CLT) panels exposed outdoors for 30 days as a simulated floor (Morrell et al. 2018). Panels gained nearly 30 percent mass over the exposure. The CT scans suggested that moisture accumulation was highly variable but was concentrated in the non-edge-glued joints (Fig. 1). Postdrying examination revealed the presence of numerous internal cracks (Fig. 2). These results highlighted the risk of moisture intrusion for panels comprising dimension timber, but these risks need to be understood for new products entering the market.

Mass ply panels (MPPs) are one such material (APA—The Engineered Wood Association [APA] 2025b). MPP is composed of hot-pressed nominal 25-mm 9-ply Douglas fir veneer billets cold pressed to create larger mass timber panels and are certified as a CLT under APA PRG 320 (APA 2025a). Although MPPs are not new, development of production capacity has

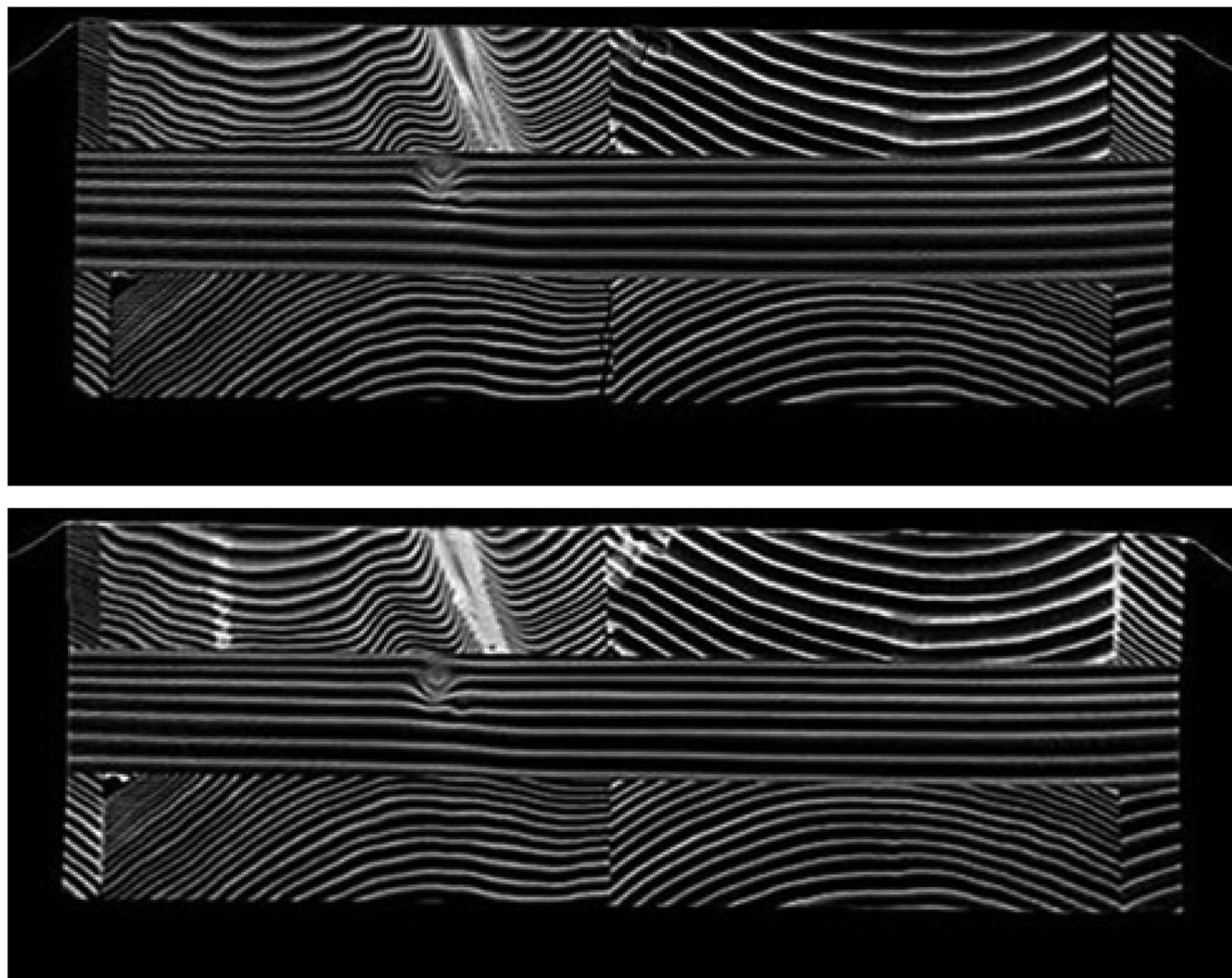


Figure 1.—Computed tomography scans showing a cross section of a Douglas fir cross-laminated timber panel before and after 30 days of exposure to natural rainfall. Note the brighter areas at the non-edge-glued joints after wetting indicating higher density (Morrell et al. 2018).



Figure 2.—Example of a Douglas fir cross-laminated timber panel section exposed to natural rainfall for 30 days and air dried for 2 years showing checking and delamination.

stimulated renewed interest in this product in commercial construction in North America. Unlike non-edge-glued CLT, where the pathways for moisture intrusion are primarily from the upper surface and the non-edge-glued areas, the multiple bond lines in MPPs create a more complex pathway for moisture intrusion. However, wood is still hygroscopic; lathe checks, small gaps in the glue lines, and scarf joints all present pathways for moisture intrusion into the panel. Understanding how moisture migrates into this material will help manufacturers and builders develop best practices for managing moisture during construction.

Given the value of effectively managing moisture in mass timber floors and the growth in the use of veneer-based mass timber, it is imperative to better understand moisture ingress into veneer-based mass timber. Commercially available sealants are a possible tool for reducing moisture uptake, and compelling evidence shows that these treatments can prolong the useful life of other veneer-based products (Williams 2010). However, the potential value of these products during construction of veneer-based mass timber remains unclear. To help fill these gaps in understanding the literature, an experimental program was devised using a commercial veneer-based mass timber material, MPP, with the following objectives: Assess moisture movement into MPPs due to short-term ponding on the material face and assess whether the addition of a water repellent to the MPP surface slowed the movement of moisture into the material due to ponding during construction.

Materials and Methods

The mass timber for this study was Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) MPP. Although composed of veneer, MPP is certified as a CLT under APA PRG320 (APA 2025a).

The layup was F16, which contains nine plies per 25-mm-thick hot-pressed section with seven plies running in the longitudinal direction and two plies transverse, forming five layers per hot-pressed section (APA 2025b). The individual 25-mm hot-pressed billets were then pressed together with adhesive to form MPP, with this study using 75-mm-thick MPP.

The MPP was cut into 100-mm by 153-mm-long sections that were conditioned to stable mass at 20°C and 65 percent relative humidity. The exposed veneer edges were sealed with an elastomeric coating to retard moisture loss. A 25-mm-wide closed-cell gasket was attached around the sides with caulking to create a well at the top. The gasket was also secured with staples to minimize leakage. Later versions eliminated the elastomeric because there was little evidence of leakage from the sides of the blocks (Fig. 3). Nine assemblies were left as noncoated controls, whereas the upper surfaces of an additional nine samples received two coats of a high solids water repellent applied with an absorbent paper towel with 10 minutes between coats. The water-based coating (LotusPro, Arxada, Alpharetta, Georgia, USA) contained 46 g/L of volatile organic compounds. The assemblies were weighed before and after each coat to determine net water-repellent application. Each block received an average of 1.82 mg/cm² of solution.

The samples were weighed, water was added to a depth of approximately 10 mm in the well, and the assembly was placed into a plastic bag to retard drying. The samples were incubated for 1, 4, or 7 days. Additional assemblies without water repellent were exposed for 18 and 24 days to assess the effect of prolonged wetting. Water was added as needed. Each time point was replicated on a minimum of three assemblies. The assemblies were removed at the appropriate time point, the water was poured out of the well, and the wetted surface was blotted with a paper towel to remove excess moisture.



Figure 3.—Examples of a mass ply panel block: before sealing (top); sealed with the water well (bottom).

The assembly was weighed, and the difference between initial and final mass was used to calculate total water uptake over the exposure period. The replication varied slightly with time as a result of the opportunity to collect data on additional samples (Table 1). Non-water repellent-coated samples were left up to 24 days to better understand the potential for increased moisture movement inward from the exposed surface over time.

The gasket and staples were removed, and the block was cross-cut into nine ~17-mm-thick sections that were then cut into six ~13-mm slices each with approximately four veneers (Fig. 4). The 54 samples per block were then weighed and oven-dried at 103°C before being weighed again to determine moisture content. Final moisture contents included both the

Table 1.—Moisture content of mass ply panel samples over time with and without a water repellent.

Exposure time (d)	<i>N</i>	Control		<i>n</i>	Water repellent	
		Moisture content			Moisture content	
		Mean (%)	COV ^a (%)		Mean (%)	COV (%)
1	3	15.72	2.4	3	16.62	51.1
4	3	22.11	11.4	3	13.82	18.0
7	4	23.49	18.8	3	15.48	8.6
18	3	28.06	18.0	—	—	—
24	4	31.36	6.5	—	—	—

^a COV = XXXXX.

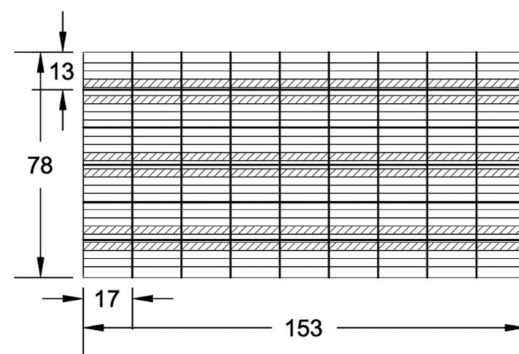


Figure 4.—Diagram of mass ply panel moisture distribution specimens, showing the location and depths of cuts. All units in mm.

original conditioned mass as well as any moisture that moved into the wood from the wetting exposure.

The data were averaged by distance from the surface for the nine crosscuts from each block, and then these data were used to create maps showing moisture distribution as a function of cross-section location. These maps are primarily visual and intended to show the rate and degree of moisture penetration inward when subjected to overhead wetting.

Results and Discussion

Moisture uptake in the blocks increased markedly in the first 24 hours after wetting in both nontreated and water repellent-treated samples (Table 1). The moisture content of the blocks was calculated using the total wet and dry masses of all individual cut pieces from a single block. Although this may have some slight variations from the true moisture content, because of removed material in the saw kerf, it was assumed to be minimal. Moisture uptake continued to increase for the next 3 days in nontreated samples and then stabilized at 7 days, whereas moisture uptake remained lower in the treated samples after 7 days of wetting. A related study of prolonged water exposures with noncoated samples showed that moisture contents exceeded 30 percent after 24 days of wetting (Fig. 5). These levels would be suitable for microbial attack (Fig. 5). Moisture was concentrated in the first three to four

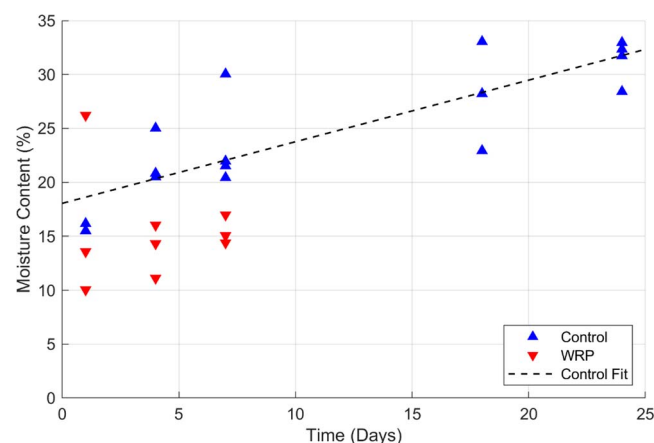


Figure 5.—Moisture content of mass ply panels that were exposed to wetting for 1 to 24 days without a water repellent and 1 to 7 days with a water repellent. Fit line is for non-water-repellent data with equation $Y = 0.572x + 18.044$ and $R^2 = 0.709$.



Figure 6.—Cross cuts of an mass ply panel without a water repellent showing moisture intrusion (darkened area above the marker) after 7 days of wetting.

veneers beneath the surface in each panel (Fig. 6). Leakage issues led to some wetting of the underside of the test pieces, which skewed the data, but the overall trend was sharply decreased moisture levels with distance from the upper wetted surface (Fig. 6).

Dissection of blocks following wetting supported the initial observation that water was rapidly absorbed by the upper veneers and then slowly moved deeper into the panel. Moisture contents in the upper 15 mm of non-water repellent (WRP) treated panels increased from ~12 percent at time zero to ~44 percent in 1 day and ~66 percent after 7 days. Levels in the 15- to 30-mm zone were similar to the starting point for

the first 4 days, then gradually increased to ~20 percent after 7 days of wetting (Table 2). Although the moisture levels near the surface were well above those required for initiation of fungal decay, the levels further from the surface remained below that level after 7 days (Zabel and Morrell 2020). It is worth noting that moisture will continue to diffuse inward over time, even as the upper surface is allowed to dry. This would eventually result in elevated moisture levels deeper in the wood that would support fungal growth. Parallel studies on CLT have found moisture intrusion further inward from the surface, but CT scans suggested that these increases were primarily associated with non-edge-glued joints (Morrell et al. 2018).

Moisture levels in WRP-coated panels also increased after 1 day of wetting, but the levels were approximately one-third lower than those in the non-WRP-treated samples and then remained stable for the next 6 days. Considerable variation in moisture levels also occurred in the outer 15 mm of the WRP-treated panels, especially in the first 4 days after wetting, suggesting that some of the variation reflected coating application. These variations emphasize the value of proper uniform application. Moisture levels in the next zone inward remained about one-third lower in WRP-coated samples.

Water repellents are often misconstrued as complete barriers to water ingress; however, their primary benefit is to shed water until the surface either dried or the water is physically removed, as seen by the two chapters on wood finishes in the *Wood Handbook* (Williams 2010, Hunt 2021). The results in the current study clearly showed that the WRP markedly reduced water absorption near the surface.

The MPP presents an especially different geometry for moisture intrusion. Lathe checks in individual veneers can facilitate moisture ingress, but the presence of glue lines every ~3 mm creates a discontinuous path that could inhibit further diffusion inward. However, previous plywood studies suggest that gaps in bond lines can allow water movement, albeit at lower rates than would occur in nonbonded veneers clamped together (Bolton and Humphrey 1994). Thus, prolonged wetting will allow moisture to move deeper into the panel. This creates issues related to panel stability and subsequent drying. Rapid drying is more likely to lead to disruption of the wood and resin interface, resulting in delamination, whereas prolonged wetting is likely to support fungal attack (Siau 1995; Mahapatra et al., 2021). These contrasting issues make moisture exclusion an essential aspect of panel installation. The results clearly show that WRP treatment reduces moisture uptake, but the

Table 2.—Moisture contents of sections cut from different distances inward from the surface of nontreated and WRP treated MPP blocks exposed to moisture for 1 to 7 days.

Distance from surface (mm)	Moisture content (%) ^a					
	1 Day		4 Days		7 Days	
	Control	WRP ^b	Control	WRP	Control	WRP
0–15	43.82 (6.07)	31.69 (55.47)	43.71 (15.31)	31.04 (49.55)	65.94 (5.93)	34.99 (18.61)
15–30	13.30 (5.86)	18.13 (68.73)	13.83 (7.52)	12.68 (17.43)	19.20 (13.44)	12.51 (10.07)
30–45	10.21 (5.00)	12.86 (42.22)	13.02 (14.59)	10.32 (3.29)	11.12 (5.85)	10.66 (9.29)
45–60	9.55 (8.59)	13.30 (50.00)	12.02 (4.49)	10.08 (1.09)	11.39 (10.01)	10.42 (4.13)
60–75	9.60 (8.44)	11.56 (36.51)	13.59 (6.03)	10.09 (0.69)	10.99 (4.09)	11.01 (9.99)
75–90	9.83 (4.27)	12.72 (45.99)	40.50 (10.30)	10.11 (2.47)	10.94 (5.03)	12.50 (22.96)
Avg.	16.05 (6.23)	16.70 (45.93)	22.78 (11.11)	14.05 (59.64)	21.60 (7.18)	15.33 (63.08)

^a Values in parentheses represent the coefficient of variation.

^b WRP = water-repellent preservative; MPP = mass ply panel.

further benefits would accrue if these coatings were supported by rapid removal of water following rainfall events that minimized direct exposure time to pooled water on the floor. One aspect worthy of further study is the potential effects of a water repellent on subsequent drying of the water that intrudes.

It is useful to visualize moisture movement into the substrate (Figs. 7 and 8). The panels comprised a mixture of Douglas fir heartwood and sapwood, and there was no way to easily determine whether a particular veneer comprised either material. However, this species has a relatively thin sapwood, meaning that most of the veneers will be composed of heartwood. Sapwood is generally permeable and easily penetrated by liquids. Douglas fir heartwood is usually much less permeable and should resist moisture movement (Siau 1995). The combination of heartwood and the presence of glue lines should slow moisture movement from the surface inward. Thus, although moisture ingress into the first four veneers was relatively rapid, further movement inward was more limited after 7 days. Increased moisture levels further inward from the surface will complicate drying after the building is completed and increase the risk of internal stresses that may lead to bond failure. It is unclear what effect any internal stress will have on the panel once in service. This merits further study, perhaps with larger samples where any residual stresses might become more important.

Moisture management requires a comprehensive, integrated approach beginning at the point of manufacturing that includes close adherence to maximum moisture tolerances, protection from wetting in transport and storage on site, and finally, rapid removal of standing water during construction. Failure to remove water that accumulates from periodic rainfall events clearly results in rapid water absorption on the surface, and prolonged wetting ensures that this moisture moves deeper into the wood where it will complicate drying. Taping of joints during construction and factory-applied water-repellent barriers can help mitigate absorption but will never completely limit ingress.

Conceptually, moisture management to minimize the risk of fungal and insect attack is not new (Verrall and Amburgey 1980, Rosenberg and Wilcox 1982). A well-managed program to minimize moisture ingress during erection might incorporate the following:

1. Application of a water repellent at the time of manufacturing—ideally after machining.
2. Wrapping in a water-resistant barrier for transport and storage on site.
3. Just-in-time delivery to minimize the risk of damage to the barriers on site.

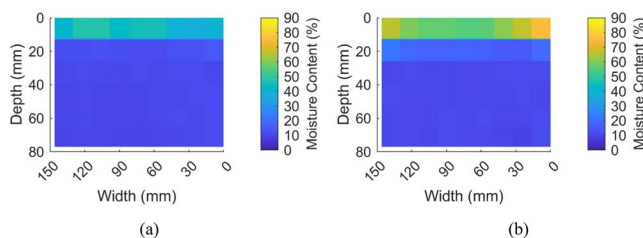


Figure 7.—Examples of moisture distribution in MPP subjected to wetting for 1 (a) or 7 (b) days where increasing yellow signifies higher moisture levels.

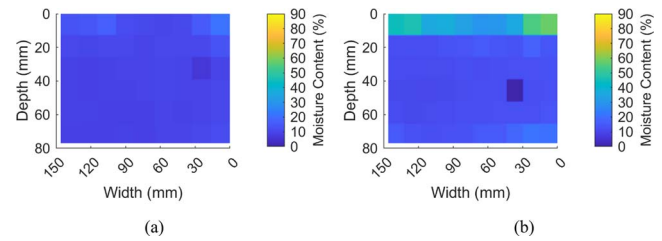


Figure 8.—Examples of moisture distribution in water repellent-coated mass ply panel subjected to wetting for 1 (a) or 7 (b) days, where increasing yellow signifies higher moisture levels.

4. Taping floor joints as soon as possible to minimize water ingress to the levels below.
5. Capping of any upright members to minimize downward movement of rainfall.
6. Regular sweeping of any ponded water that accumulates after a rainfall.
7. Slow introduction of airflow to help dry members while minimizing deformation.

All these elements will help reduce moisture accumulation until the building is covered.

An equally critical element in building performance is monitoring moisture levels at selected locations over time after construction is complete. The results clearly illustrate how quickly moisture can be absorbed. All buildings eventually leak. Placing moisture sensors near toilets, kitchens, and in the roof will allow building managers to detect and address moisture changes resulting from plumbing failures or leaks before these reach levels that lead to mold or decay. These sensors are not specific for wood because monitoring makes sense for any building regardless of the material used.

Conclusions

Moisture intrusion into MPP occurred within 24 hours but was concentrated in the upper four plies after 1 week of wetting. A water-repellent coating slowed, but did not completely preclude, moisture uptake over the test period. Rapid moisture ingress highlights the importance of minimizing exposure and removing any water accumulation that occurs to minimize the need for postconstruction drying. Ultimately, minimizing wetting represents a more practical approach for managing moisture during construction.

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