Field Observations and Laboratory Tests of Water Migration in Walls with Shiplap Hardboard Siding

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ABSTRACT

In a number of legal cases across the country it has been alleged that hardboard siding performs poorly from a moisture point of view and thus is not a satisfactory siding material. In one particular case involving an apartment complex of about 400 units in the San Francisco Bay area, decay of both hardboard siding and wood trim as well as other wood members was noted and has been documented for this paper. It was clearly found that the decay was primarily caused by substantial amounts of liquid rainwater leaking behind the siding and other wood members. However, other decay or deterioration (e.g., swelling) of the siding was noted in areas where liquid water intrusion was not directly observed. We speculated that liquid water might move laterally behind the siding from leak sites in the building envelope, and that might explain the existence of siding swelling observed at locations some distance horizontally from otherwise obvious leak sites. Deterioration of the hardboard siding also was found to be caused by a number of other installation problems such as allowing the bottom edge of the siding to be in direct contact with concrete. We also noted swelling of some bottom courses of the siding and speculated that standing water on concrete paving might be wicking up the gypsum sheathing behind the siding. It also was alleged that rainwater was wicking up between the siding laps and causing swelling and cracking of the siding. In addition, it was suggested that hardboard absorbs water "like a sponge" when compared to other widely used siding materials and contributes to deterioration of wall materials, including gypsum and oriented strand board (OSB) sheathings.

To test the validity of these hypotheses, we undertook a series of laboratory tests of water migration in mock-up walls with hardboard siding. Every effort was made to duplicate the construction and weather conditions at the apartments. One series of tests run on walls with both hardboard siding and redwood siding involved examining the lateral migration of water introduced between the siding and the 15 lb building paper. A second set of tests involved spraying water on two test walls to check for the existence of wicking between the laps. Another series of tests involved determining the vertical height and effect of capillary wicking in gypsum sheathing, gypsum board, and hardboard siding whose bottom edges were submerged in water. A fourth set of tests involved introducing water between the siding and building paper in four walls with different types of siding and comparing the impact on the OSB sheathing and the siding materials. A fifth set of tests involved submersing hardboard siding and other materials in water to determine their relative water absorption characteristics.

The setup of the tests will be described in detail along with the water migration test results and conclusions. A number of new and important findings will be presented. The moisture performance of hardboard siding along with its suitability as a siding material will be discussed in light of the test results.

INTRODUCTION

Hardboard has been widely used for residential lap and panel siding in the U.S. One estimate (Spalt 1996) suggests that as many as 20% of all U.S. homes have been sided with hardboard over the last 20 or so years. According to the American Hardboard Association (Peterson 1998), 28 billion ft^2 of hardboard siding were installed on U.S. residences between 1964 and 1996. Assuming 1,200 ft^2 per dwelling, that corresponds to about 20 million homes. Given such large numbers, it is not surprising that there would be legal cases asserting that the siding was not performing properly. There have been a number of different types of alleged poor performance of the siding itself, including buckling or bowing, swelling or

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"brooming" of the bottom lap edge, swelling or puckering around nail heads, wicking between laps leading to deterioration, a propensity to slowly swell over time due to water vapor absorption—leading to subsequent liquid water intrusion and deterioration, and readily soaking up liquid water that might leak behind the siding and cause deterioration of the plywood or oriented strand board (OSB) sheathing. Oftentimes, it is simply alleged that the siding will have a service life shorter than the warranty period because it will deteriorate with time, or that it is an inappropriate siding material for a particular climate and should be replaced. Unfortunately, few, if any, of these allegations are ever substantiated with unambiguous scientific evidence, such as might be found in peer-reviewed scientific journals. Typically, they are hearsay or simply believed to be true or postulated without proof. Unfortunately, if repeated often enough, people start to believe the assertions as though they are based on fact. In fact, we know of no published results of scientific tests on properly installed and maintained hardboard siding that verify any of these allegations. To the contrary, in the few cases of published research test results involving hardboard siding, it performs quite well and does not exhibit any of the alleged poor performance (River 1994; TenWolde et al. 1998).

There is no question that in some instances hardboard siding has buckled, broomed, swelled around nail heads, or otherwise deteriorated, including rotting. These problems are alleged to be characteristic of the siding itself. It is our experience, after having inspected many thousands of residences with hardboard siding, that in almost every case the problems are related to the improper installation of the siding and/or related building envelope components or lack of proper maintenance. There are cases where the installation instructions have not been followed, and that has led directly to such deterioration of the siding. For example, buckling or severe bowing most often is caused by improper nailing. It can also be caused by following the contour of misaligned framing. Liquid water absorption leading to swelling or rotting of hardboard siding does occur when the siding is installed so the bottom edge of the lowest course is in contact with the ground, concrete, or masonry or the backside is in contact with concrete or masonry. Swelling may occur over long time periods (years) if the bottom lap edge of the siding is not painted. That is particularly true if the bottom siding course is too close to the ground such that it can be adversely impacted by rain splashback or spray from landscape sprinklers. The siding also may rot when flashing is improperly installed such that a large amount of liquid water gets into the wall cavity and soaks the siding from its backside. Not surprisingly, most of these problems occur with any type of wood-based siding, although perhaps not to the same extent. People tend to forget these problems are not unique to hardboard siding. For example, it is our collective experience that T1-11 plywood siding often exhibits many of these problems. Also, class action suits associated with widespread moisture problems with OSB siding are well known. Even walls with cedar and redwood siding exhibit problems if not properly installed and maintained. While those naturally rot-resistant sidings do not rot as easily or as quickly, if large amounts of water get behind those siding materials because of poor flashing or other leaks, then the materials inside the wall cavities may deteriorate substantially before there is any external evidence of moisture problems inside the walls.

Manufacturers of hardboard siding do in fact test their siding following ASTM D 1037 standard test methods, but typically that is primarily aimed at providing product that meets voluntary American Hardboard Association production standards (ANSI/AHA A135.6). However, the focus is on the product rather than on the system in which the hardboard product is a component. Some manufacturers do some long-term moisture performance testing, such as on exposed weather fences outdoors (primarily to examine paint performance) or in laboratories where the product is exposed to accelerated, severe wetting and drying cycles for the weather equivalent of many years. Generally speaking, the siding that is on the market passes these tests (e.g., with minimal swelling or permanent set), but unfortunately these tests are proprietary and are not published in the open literature. More importantly, there have been few if any tests of complete wall systems where the focus is on the moisture performance of the whole wall.

One set of unpublished laboratory tests conducted by one of the authors involved determining the amount of water intrusion into a wall cavity allowed by improper flashing detailing, including window flashing and flashing at the junction between siding and a shed roof. Water was sprayed on a series of different test wall systems with the backside of the walls depressurized to simulate wind-driven rain following the ASTM 331 test protocol. The improper flashing allowed significant amounts of water (many gallons) to enter the wall cavity in a three-hour test period, whereas there was essentially no intrusion with proper flashing. Those test results clearly showed that improper flashing could easily lead to serious moisture performance consequences.

Sometimes it is suggested by those opposed to the use of hardboard that what is needed is to paint the backside of the hardboard to protect it and to provide capillary breaks between the laps to prevent wicking. One reason that hardboard is not back primed is to allow it to breath on the backside and so to allow any moisture that does get into the siding to more readily get out. It has been reasoned by manufacturers that painting it on the backside would actually hinder that process (Spalt 1996). Tests have been completed (TenWolde et al. 1998) on hardboard siding with and without back priming exposed for 2½ years on test buildings in Florida, where incidentally the likelihood of decay occurring is the highest in the country (Scheffer 1971). They found that "backpriming the siding had no beneficial effect on moisture content, and there were indications that backpriming was counterproductive." In fact, all the siding stayed quite dry and in excellent condition, and thickness swelling was less than 3% (average 8 mils or 2%) during the entire exposure.

Whether a capillary break between laps is necessary depends on whether capillary wicking between the laps actually exists. Our general experience in removing the siding from numerous walls is that on occasion we do see water staining on the backside of the siding. We believe the staining is from rainwater getting behind the board as a result of leaks rather than wicking between the laps. Most of the siding we inspect when it is removed from a wall has no water staining on the backside. If wicking between siding laps indeed were so common, then we would expect to see signs of it much more often and much more uniformly.

In unpublished laboratory tests, severe wetting and drying cycling of hardboard siding was conducted over a period of many years. There was no wicking between the laps observed. Furthermore, in other unpublished tests run by one of the authors, two pieces of hardboard shiplap siding were positioned one atop the other on edge and immersed in water in an aquarium. The water level was maintained just touching the bottom lap edge of the top piece for 72 hours to see if wicking would occur. There was no wicking observed at the end of the test when the two pieces were separated and inspected. Similar tests were completed with regular lap hardboard siding for 24 hours, and the results were the same. It is our strong belief, based on the lab test results and our collective field experience, that wicking between laps generally does not occur with hardboard shiplap or (other profile) siding. Nonetheless, we felt that further testing under dynamic water spraying conditions to simulate wind-driven rain would be worthwhile to help settle this issue.

CASE STUDY FIELD OBSERVATIONS

In one particular legal case involving a roughly 400-unit apartment complex in the northern California Bay area, some of the hardboard siding and associated wood trim were observed to be badly decayed. The three-story wood-framed wall construction was conventional with 0.625 in. (15.9 mm) gypsum board (sheetrock) on the interior, a polyethylene vapor retarder, R-11 (RSI-1.9) insulation, 0.375 in. (9.5 mm) OSB sheathing (with additional 0.625 in. [15.9 mm] gypsum sheathing in some locations), 15 lb building paper (actually 15 lb roofing felt), and 0.5 in. (12.7 mm) shiplap hardboard siding with factory primer, site-applied oil-based primer, and site-applied vinyl-acrylic paint. The paint was generally in very good condition, with good coverage on both the face of the siding as well as the drip edges. About 96% of the hardboard siding was deemed to be in very good condition. Thus, for the vast majority of the siding there was no deterioration of any kind noted, including decay or swelling.

We undertook destructive testing that involved removal of deteriorated and nearby siding in over 60 different locations. We found that the swelling and decay were caused primarily by the regular intrusion of abnormally large amounts of liquid water behind the siding and other wood members. There were a number of causes of the water intrusion, but the main reason was poor flashing details. One main source of water intrusion involved rainwater that collected on many second- and third-story concrete entry landings and readily entered the wall at the wall-landing intersection where flashing was clearly improperly installed. We found many finger- and pencil-sized holes, and we estimated that each would allow entry of many gallons of water into the wall cavities during heavy rains. That resulted in serious deterioration of the siding and the associated wood trim, as well as other wall cavity components such as the building paper and the OSB and gypsum sheathing.

An example is presented in Figure 1 that shows siding that was later removed from three stories of wall in an area where such a point source of water caused swelling and decay below it. The values marked on the siding are its moisture contents measured with a pin-type moisture meter. The readings of 7% to 8% above and to the left of the point leak source indicate the siding is normally dry in those areas, whereas the readings below the leak site are much higher and indicate the siding has been wetted by the water leaking behind the siding (values of 99 written on the siding indicate the moisture content is above the 40% upper limit of the meter). Figure 2 shows the same location after the siding had been removed for inspection. The deterioration noted is directly below the point leak source found where flashing at the intersection of the wall

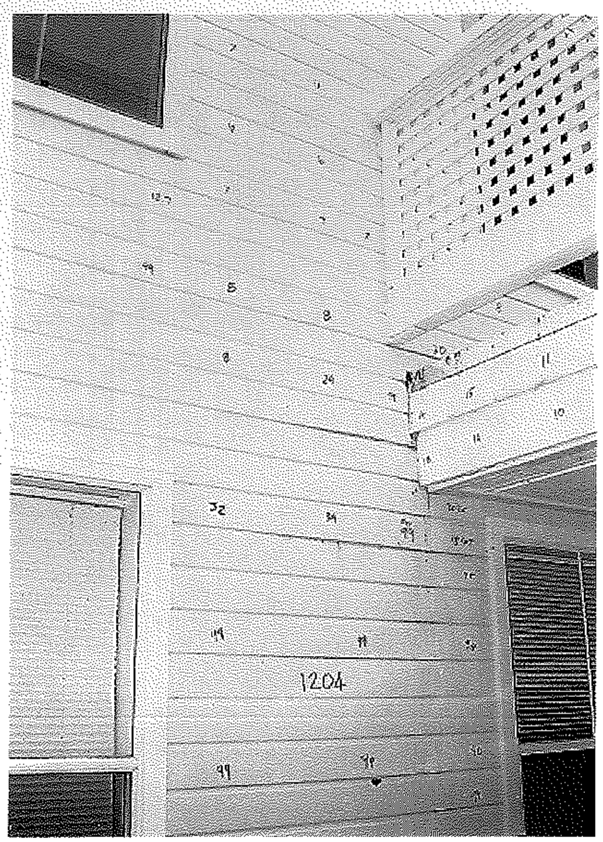

Figure 1 *Front side of hardboard siding near and below third-story point leak source.*

Figure 2 *Siding removed from area near and below third-story point leak source.*

and the concrete entryway deck was improperly installed. That typical construction condition throughout the apartment complex allowed large amounts of water that collected on the concrete entryway decks to enter the walls and flow behind the siding.

Water also entered the walls around the one-by-three wood window trim that was not properly flashed or caulked and also through leaks in vertically stacked window joints. There actually were a large number of frequently occurring conditions where we were able to show that water obviously got behind the siding.

As noted above, in a number of locations we found that water entered at a third-story landing-wall intersection and caused serious siding swelling and decay below that point source. However, we also noted swelling in other nearby locations that were not below a point source. So we conjectured that water behind the siding might be moving laterally and then causing deterioration of the siding well away from a point source.

We also saw slight but noticeable swelling of the face of some siding in a breezeway, along with micro-cracking of the paint on the bottom of the shiplap drip edges (small cracks that run along the length of the drip edges caused by thickness swelling of the siding that leads to cracking of the paint). Some of that siding was removed, and we noted some water staining on the opposite backside of that siding. However, while there was no obvious nearby source of water in the vicinity of the swelling, we did note leakage of water into the wall at the wall ends in corners, especially high up on the wall. We also noted that there was obvious swelling and deterioration near the bottom of the wall (primarily in the lower 2 ft). We felt that might be associated with water wicking up the gypsum sheathing behind the building paper and the siding since the sheathing was not properly flashed and protected at its base from rainwater. Some of the walls mistakenly used regular indoor gypsum board instead of the more water-resistant gypsum sheathing rated for exterior use for fire protection. Generally speaking, most of the swelling occurred within the lower 4 ft of the wall. There were few, if any, problems higher up on the walls, except where there were obvious leaks. Furthermore, there was little or no siding buckling anywhere in the project.

In addition, we noted instances where siding was swollen because it was in direct contact with concrete, including the bottom of the lowest course being embedded in concrete, or because the unpainted bottom edge of the bottom course was too close to grade or concrete such that rainwater was splashed up onto the unprotected bottom of the siding and wetted it. All these cases were clear violations of the manufacturer's application instructions.

Finally, there was evidence of mold and mildew as well as other deterioration, such as rotting of the OSB sheathing in many locations where large quantities of liquid water had gotten behind the siding. It was alleged that the hardboard siding was particularly susceptible to soaking up water like a sponge and, thus, causing the deterioration of the sheathing.

THE NEED FOR LABORATORY TESTS

Based on our site inspection findings, we decided that it would be worthwhile to undertake a series of controlled laboratory tests to help explain some of the field observations. Specifically, we wanted to do experiments to

1. determine the extent and mechanism of lateral water migration behind the siding,
2. determine whether wicking between the siding laps occurs,
3. determine the extent of capillary wicking of liquid water up through gypsum sheathing and any subsequent effect on either the OSB sheathing or the hardboard siding, and
4. compare the effect on OSB sheathing of water intrusion behind four different types of siding.

The four different types of siding included hardboard shiplap siding as well as three other commonly used siding types (OSB panel siding, T1-11 plywood panel siding, and cellulose-reinforced cement lap siding). Cedar and redwood siding were not included in these tests because they are not commonly used in multi-family apartment-type applications because they are much more expensive (about four to five times more).

DESCRIPTION OF THE LABORATORY TEST SETUPS AND PROCEDURES

Tests were undertaken in a mechanical engineering laboratory at a university in Oregon. All test walls were of typical two-by-four construction with studs on 16 in. (0.41 m) centers; they were constructed in the laboratory like those found in the field. Except where noted, they all had an outer cladding layer, 15 lb (0.7 kg/m^2) building paper, 0.625 in. (15.9 mm) gypsum sheathing, and 0.375 in. (9.5 mm) OSB sheathing, but they did not contain any insulation, warm-side vapor retarder, or interior gypsum board. A test wall plan section is shown in Figure 3. For all the tests, the 0.5 in. (12.7 mm) hardboard siding pieces were a 15.5 in. (0.394 m) high shiplap design that spanned the complete width of the test walls. There were no butt end joints in any of the tests. The test walls were of nominal 12 ft, 8 ft, or 4 ft (3.7 m, 2.4 m, or 1.2 m) widths. Some were 8 ft (3.7 m) high, and some were 4 ft (2.4 m) high. The hardboard siding was of the same profile/type and roughly the same vintage as that found at the field site; it had been stored in a warehouse and had never been used. The only exception was the hardboard siding used in the four-wall siding comparison test. That hardboard came from an area exposed to the weather at the apartment complex. All siding pieces had a factory-applied primer coat and a single layer of exterior paint applied with a roller and brushed at the drip edges.

In almost all the tests, the moisture content of the boards was measured before and after any testing with either a capacitance-type surface moisture meter with a nominal half-inch penetration depth or a temperature and species corrected two-pin electric resistance type moisture meter. Additionally, in a number of the tests the individual hardboard siding pieces were weighed before and after the tests. Laboratory relative humidity readings also were recorded. All salient conditions and findings were recorded photographically and on video.

Lateral Water Migration Tests

These tests were designed to introduce water into a wall at a point source behind the siding and then observe the extent of lateral migration of the water behind the siding. Three 8 ft (2.4 m) high by 12 ft (3.6 m) wide walls were constructed. The first wall had shiplap hardboard siding with only the factory primer coat. None of the seams between pieces was sealed. The second had redwood siding in a similar shiplap pattern with an oil-based primer coat on all surfaces (as is common in Northern California) and an oil-based exterior finish paint coat. About half of the seams between pieces were randomly sealed by the exterior paint. The third wall was constructed the same as the first, except it had a coat of exterior paint rolled on similar to that in the field so that about half of the gaps or seams between the shiplap pieces were painted closed (in a random pattern).

Liquid water was introduced between the siding and the building paper in the upper left-hand corner of the test walls. It entered through a funnel and then through a flattened 0.25 in. (6.4 mm) diameter piece of soft copper tubing. In the first two tests the water was introduced at a rate of 7.5 gallons (or 1 ft^3 [28.4 L]) in a 24-hour period. That total amount corresponded to the amount of rainwater estimated to enter the walls at leaks at the intersection of the siding and concrete entryway landings. The size and slope of the landings along with an

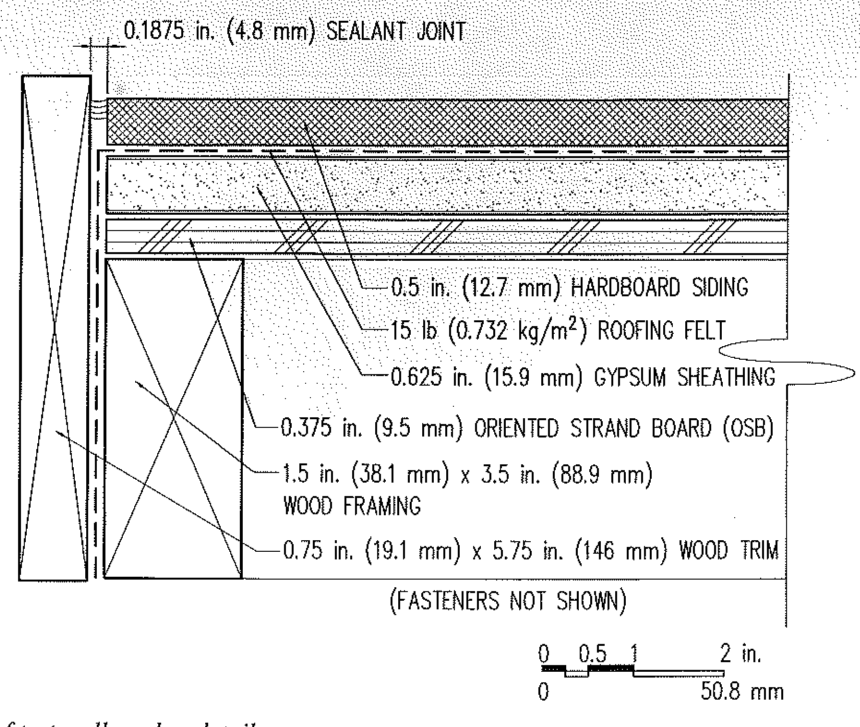

Figure 3 *Section of test walls - plan detail.*

assumption of 3 in. (76.2 mm) of rain in a three-day period was used in estimating the amount of water that might enter the wall. The water was poured in by hand at a rate of about 2 gph (2.1 mL/s) until the full amount was poured in. These two walls were opened up after a 24-hour period that began with the initial water pour. The third wall test ran four weeks. In that test, the amount of water introduced was felt to be typical of what might occur due to leaks during a month in the rainy season. The test water was introduced using an irrigation drip system with an electronic timer control for 12 hours a day (12 on, 12 off) during the first two days at a rate of 0.5 gph (0.53 mL/s) or 6 gal/day (22.7 L/day). After the first two days, the duration of on time of the drip system was reduced to 2 hours every 12 hours (2 gal/day [7.6 L/day]) while maintaining the same 0.5 gph (0.53 mL/s) flow rate. Then two days later the drip system was on for one hour a day to provide 0.5 gal/day [1.9 L/day]. For all the walls in all the tests, the water that drained out of the walls (or off the exterior of the siding in the spray tests) was caught in a collection basin and then pumped to a drain.

Water Spray Wicking Tests

These tests were designed to spray water onto a wall to simulate wind-driven rain and then open up the wall to see if any wicking up between the laps occurred. Two 8 ft (2.4 m) high by 8 ft (2.4 m) wide walls were constructed. The first test wall had an oil-based exterior paint applied according to the siding manufacturer's instructions, while the second had the same vinyl-acrylic paint applied as was used on site. A photograph of the test setup is shown in Figure 4.

Water was sprayed on to the walls for 15 minutes once a day at a rate of 0.14 gpm (0.147 mL/s) from each of two spray heads for seven days. That amount was based on an estimate that assumed the following:

- the highest amount of rain at the field site for a one-month period in the prior forty years (10 in. [0.25 m] of rain in January according to National Climatic Center data),
- an average January windspeed of 9 mph (14.5 km/h),
- a raindrop terminal velocity of 90 mph (145 km/h) (Miller and Thompson 1970; Mason 1971),
- a maximum of one-third of the rain hitting any given wall orientation, and
- an accumulation of rain at the bottom course of siding of a 30 ft (9.1 m) three-story wall.

It was assumed that this was a worst-case amount of water to spray on a wall. There were two side-by-side low-flow irrigation-type spray heads for these tests, each spraying at a rate of 0.14 gpm (0.147 mL/s). The water from each spray head impacted the wall over a circular area of about 2.5 ft (0.76 m) in diameter. The center of each spray pattern impacted the very top of the wall at about the one-third width point, and the water ran down the siding from there. The 15 minutes a day duration of water spray was controlled by an electric timer that turned

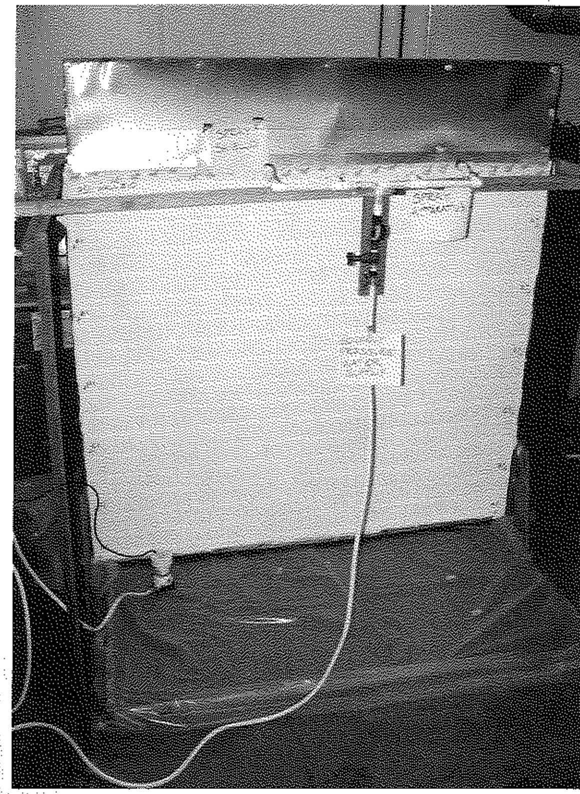

Figure 4 *Wicking test spray wall setup.*

on a water pump. While the 15 minutes a day duration may seem short, a large amount of water hit the wall during that period. It took about three to four hours for the water droplets on the drip edges to completely dry off. If we had sprayed for a longer duration, then we would have had to spray with a spray nozzle that had a lower flow rate. We tried a number of spray nozzles with different flow rates and found the one we used had about the right size water droplets; lower flow rate nozzles had too fine a mist that did not properly simulate the size of rain droplets that hit a wall.

In both tests, the water was sprayed for seven consecutive days and then the wall was opened up by removing the siding. Before and after test board moisture content was compared using the surface-type moisture meter, and any change in weight also was determined.

Gypsum Sheathing, Gypsum Board, and Hardboard Siding Capillary Wicking Tests

The objective of these tests was to observe the extent of capillary wicking of water up through both gypsum sheathing and gypsum board and its effect on the OSB sheathing and the hardboard siding in the wall. Vertical wicking up through hardboard siding was examined for comparison. Three separate 4 ft by 4 ft (1.2 m by 1.2 m) test walls were built: two with 0.625 in. (15.9 mm) gypsum sheathing and one with 0.625 in. (15.9 mm) gypsum board. The walls were constructed so that the bottom paper-coated edge of the gypsum sheathing or board protruded about 2 in. (50.8 mm) lower than the bottom of the siding. That protruding bottom was submerged 0.5 in. (12.7 mm) into water (maintained at a fixed depth in a small pond). A schematic of the test arrangement is shown in Figure 5. Vertical wicking up into hardboard siding without any other wall components was measured separately for comparison purposes. The siding was submersed vertically 0.25 in. (6.4 mm) into a container of water.

The vertical extent of wicking, measured from the bottom edge of the gypsum material, was easily observed in the gypsum materials as a distinct color change in the material (the material wetted by wicking was noticeably darker than the unwetted material above it). The edge of the gypsum material was covered with building paper to reduce drying due to evaporation, but the building paper was opened up approximately once a day to observe the extent of water wicking up the material from the bottom edge. The first test involved disassembling a wall with gypsum sheathing after one day of wicking, while the second and third involved taking apart walls with gypsum sheathing or gypsum board after about four or two weeks, respectively, of wicking up in those materials. The vertical extent of wicking in the hardboard siding, as indicated by obvious dark water staining, was measured about once a day for four weeks.

Comparison Test of Effect of Water Leakage into Walls with Different Types of Commonly Used Siding on OSB Sheathing and the Siding Materials

The purpose of this test was to compare the effect of water leaking into walls with different types of siding on the OSB sheathing and also to compare the effects on the moisture performance of the siding materials themselves. Four test walls measuring 4 ft by 4 ft (1.2 m by 1.2 m) were constructed identically except that each had a different siding material: hardboard shiplap siding, T1-11 plywood panel siding, OSB panel siding, and cellulose-reinforced cement lap siding. Cedar and redwood siding were not tested because they are not widely used since they are so much more expensive than the other types. The hardboard siding was used siding that was removed from an exposed area of the case study apartments that was not subjected to any water leakage. For these test walls only, there was no gypsum sheathing, unfaced R-13 [R_{SI}-2.3] batt insulation was installed within the stud cavities, and a poly vapor retarder was installed on the inside of the walls (without any gypsum board).

Water was introduced at the top center of the walls between the siding and the 15 lb (0.7 kg/m^2) building paper twice a day for 15 minutes at a rate of 0.5 gph (0.53 mL/s), a total of 0.25 gal/day (0.95 L/day). The test ran for four months. Four identical irrigation drip heads fed from a common manifold were used to drip the water into the wall cavities through flattened copper tubing inserted between the siding and the building paper. The water either drained from the wall cavity or was absorbed within it by the various construction materials. To measure OSB sheathing moisture contents during the tests, two insulated metal pins were inserted into the OSB sheathing so their uninsulated heads were midway within the thickness of the sheathing material. Three sets of pins were installed in each of the four walls. The sets of pins were installed along the vertical centerline of the test walls with one pair centered in the top third of the wall, one pair centered in the wall, and the last pair centered in the bottom third of the

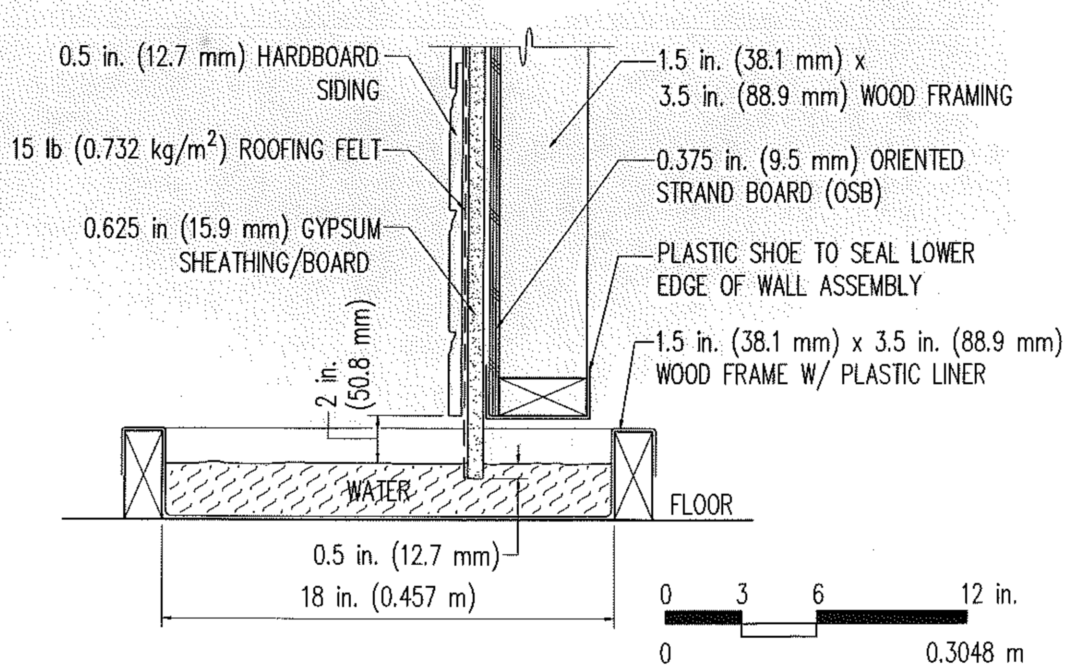

Figure 5 *Gypsum sheathing/board water migration test schematic.*

wall. These pins were connected to the electric resistance moisture meter whenever it was of interest to determine the moisture contents of the OSB sheathing in the four walls.

Water Absorption Soak Test

Small samples of hardboard siding as well as cement siding, redwood siding, pine trim, and Douglas fir stud framing material were soak tested following the general test method outlined in ASTM D 1037. While the ASTM protocol calls for a 24-hour test, we decided to test the materials over a two-week period. After many weeks of storage to reach equilibrium conditions, each of the materials was initially weighed and then submersed in a water bath. Thereafter, roughly once a day each of the materials was removed from the water bath, toweled dry, and then reweighed. From those weighings, the resultant percentage weight gain per square foot of exposed unpainted surface area was determined.

LABORATORY TEST RESULTS AND FINDINGS

Lateral Water Migration Tests

Twenty-Four-Hour Hardboard Siding Test. In the 24-hour test, water introduced between the hardboard siding without exterior finish paint (primer paint only) and the building paper was found to migrate laterally, as evidenced by water leaking through the wall or from between the laps at locations horizontally removed from a vertical line directly below the point source. The greatest lateral movement occurred at nearly a 45 degree angle from horizontal. Thus, in an 8 ft (2.4 m) high wall, the water could move as far as 8 ft (2.4 m) horizontally from the point source at the top of the wall. At the end of the 24-hour test period, the siding was removed and the siding and building paper were inspected.

Prior to these tests it had been assumed that water might move laterally primarily along the tight shiplap joints where nailing occurred. That does occur, but it is not the major mechanism for horizontal water migration behind the siding. This test indicated that once the building paper got wet from a leak, the building paper wrinkled with the major wrinkles lying in a horizontal direction such that the water was preferentially channeled horizontally. A photograph of the building paper that was exposed after the siding was removed is shown in Figure 6. While there are some relatively vertical wrinkles in the building paper, there typically were more horizontal ones. It has since been found that when building paper is wetted, it actually expands much more in the direction perpendicular to the length of the roll than in the direction of the roll (Jones and Garden 1966). Thus, the horizontal wrinkles are more than just happenstance. In fact, in examining photos from the field where siding was removed and building paper was exposed, we have noted numerous cases of the same behavior. One such example is shown in Figure 7. In the photograph, the building

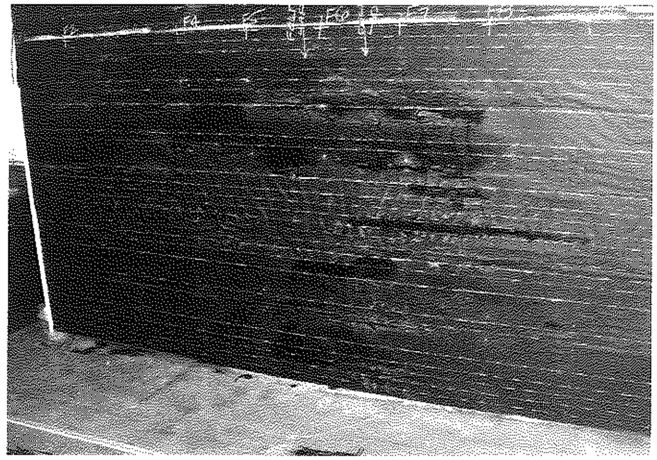

Figure 6 *Lateral water migration test wall with horizontally wrinkled building paper.*

paper has been removed from walls in a breezeway where siding was taken off, but the marks left by the building paper on the gypsum sheathing are clearly distinguishable. Note that the majority of the upper marks are horizontal, although some of the lower ones are more vertical. The wrinkles observed in the field and in the lab test are surprisingly similar. Figure 7 also shows deterioration of the bottom of the OSB sheathing due to wicking of water up into the bottom edge of the gypsum sheathing outside of the OSB.

Twenty-Four-Hour Redwood Siding Test. Seeing the wrinkles, we decided to also run a one-day test by installing redwood siding (presumed by all to be high quality siding) over the same building paper. We also decided, in painting the exterior of the siding, to randomly paint about half of the lap joints closed (or sealed), which is more typical of what is found in the field. In that test, the lateral movement was even more pronounced, with water exiting at an angle of as little as 9 degrees from horizontal. With the redwood siding, the water

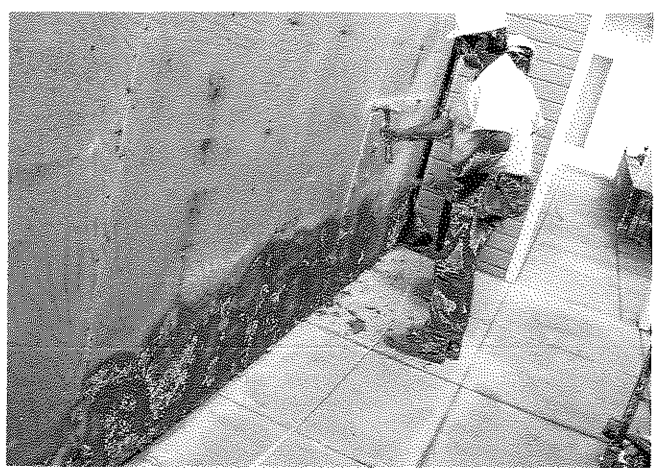

Figure 7 *Wall with horizontally wrinkled building paper marks on OSB sheathing.*

did follow the pattern in the building paper, but it also ran more readily along the horizontal lap joints of the shiplap siding. Thus with redwood siding, there was much more lateral movement than with hardboard siding.

We noted with interest that liquid water migrated through the building paper away from any nail holes and wetted the gypsum sheathing behind it within the 24-hour test period. That clearly points out that 15 lb (0.7 kg/m^2) building paper is not waterproof, and liquid water can migrate through it.

Four-Week Hardboard Siding Test. Since many of the horizontal seams or joints between the siding pieces were painted closed in the actual field site, we decided to also run the hardboard siding test with a similar wall with the siding painted such that about half of the seams were randomly closed up by paint. We also decided to run the test over a much longer duration of four weeks to see if there would be any effect on the siding or the lateral movement.

Sealing the lap joints had a pronounced effect on the horizontal movement. The least angle of water exiting from between the laps was reduced to 14 degrees from horizontal rather than the 45 degrees in the unpainted siding case. It is presumed that if the seams were all sealed with paint, as is sometimes the case when a wall is well painted, then the water might well move even more horizontally and be able to traverse large distances. It was interesting to note that the angle was 19 degrees within the first two hours of the test, during which less than one gallon of water had entered the wall. The 14 degree angle and the corresponding greatest lateral movement occurred within the first day of the four week test (as well as again on later days).

The siding was removed at the end of the four-week test period and set out on the floor to show the water pattern on the backside of the siding. The pattern is shown schematically as the darkened area in Figure 8. It clearly shows how water introduced behind the siding can readily migrate horizontally. Surprisingly similar patterns of horizontal migration of water behind siding have been observed in the field during siding removal for destructive testing.

What also is an extremely interesting finding of the lateral migration test is that by the end of the second week of the four-week test, the water absorbed by the siding had caused thickness swelling with consequent micro-cracking of the paint along the length of the bottom edges of the laps. That is identical to what has been noted in the field near leak sites and even away from leak sites. Moreover, after the first two weeks there were indications of the siding swelling such that the siding looked slightly dimpled or puckered at the nail sites and the siding itself became bowed out between the nails that were driven into studs 16 in. (0.41 m) on center both below the point source and horizontally well away from the source. That bowing and dimpling became even more pronounced by the end of the one-month test. Such bowing and dimpling was often seen on site. By the end of the second week, the crack between the boards was noted to open up as a result of the bowing and swelling. A photograph of the bowing and the

Figure 8 Water pattern on back of siding at the end of lateral water migration test.

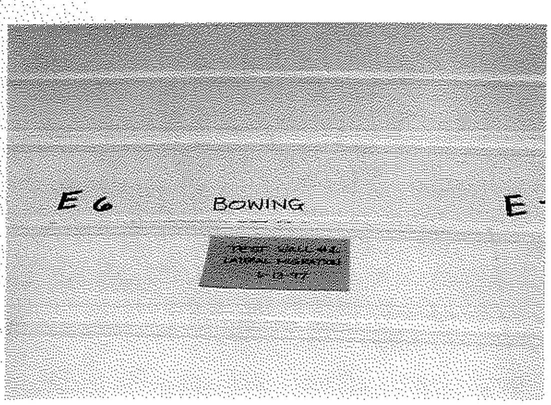

Figure 9 *Bowing and crack opening observed at end of lateral water migration tests.*

resultant crack opening that occurred by the end of the test is shown in Figure 9.

It appears from these tests that such bowing and dimpling noted in the field away from point leak sources was clearly caused by the large amounts of water known to be leaking behind the siding. The horizontal movement mechanism provides an explanation for the cause of many of the cases of isolated siding swelling and bowing well away horizontally from leak sources. Water from a point leak source at the third-story level, as was often found, could easily migrate distances of many tens of feet horizontally and cause siding damage. Unfortunately, the cause of that swelling has often been misdiagnosed in the past during field inspections or destructive testing as being caused by wicking up between the siding laps.

Water Spray Wicking Tests

Water was sprayed on each of the walls for 15 minutes a day for seven days to simulate a worst-case rain condition, and then the siding was removed and carefully inspected. There was no water staining on the backside of the siding or any other signs of wicking between the laps. There was no bowing of the siding. Moreover, there was no weight gain of the individual siding pieces, and there was no increase in the siding moisture content. Furthermore, the type of exterior paint, whether oil-based or vinyl-acrylic, made no difference in the results.

Gypsum Sheathing and Gypsum Board Capillary Wicking Tests

In the first one-day test of the wall with gypsum sheathing, the water wicked up from the bottom of the gypsum sheathing 10 in. to 10.5 in. (0.254 m to 0.267 m) in 24 hours. There was an observable increase in the moisture content of the OSB sheathing and the hardboard siding in that bottom portion of the wall. The only source of the increased moisture content in those materials was the wetted gypsum sheathing.

In the first day of the four-week test of the second wall with gypsum sheathing, the water wicked up 10 in. (0.254 m) just as in the previous test. After that, the water wicked up in ever lesser amounts each day, as shown in Figure 10. Near the end of the test, the water was wicking up the gypsum sheathing at about 1 in. (25.4 mm) per day. At the end of the four weeks, the water had wicked up 43.5 in. (1.10 m). It is notable that the highest wicking in gypsum sheathing observed at the apartment site during destructive testing was 41 in. (1.04 m).

The moisture content of the gypsum sheathing was less than 9% in the area above the line of wicking, whereas it was above 30% (the surface moisture meter limit) in the area below the line of wicking. There was a pronounced effect of the wetted gypsum sheathing on the moisture content of the adjacent OSB sheathing and to a somewhat lesser extent on the hardboard sheathing on the other side of the 15 lb building paper. At the end of the test, when the test wall was disassembled, most of the OSB sheathing was above 30% moisture content, whereas the highest moisture content in the hardboard

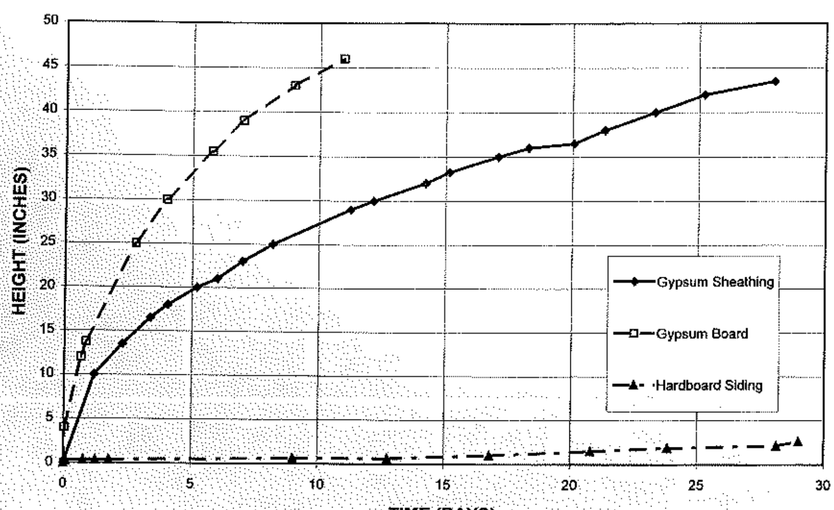

Figure 10 *Extent and rate of water wicking up gypsum sheathing, gypsum board, and hardboard siding.*

was 22% at the bottom of the siding, with values dropping linearly toward the top where it was about 11%.

The gypsum board test ran only for two weeks, in part because that material wicked much faster than the more water-resistant gypsum sheathing. In fact, the gypsum board wicked up 4 in. (0.10 m) in the first 55 minutes, 13 in. (0.33 m) in less than one day, and was rising 5 in. (0.13 m) per day after four days. It reached a height of 46 in. (1.17 m) (nearly to the top of the 4 ft [1.2 m] test wall) at the end of the two-week test period. The values of the wicking rate and water rise as a function of time are shown in Figure 10. It is seen that the wicking in the gypsum board was much more rapid than in the gypsum sheathing. By comparison, the hardboard siding had only vertically wicked up 2.5 in. (6.4 cm) at the end of four weeks.

Notably, at the end of the gypsum board test there was bowing and swelling observed on the face of the siding and at the drip edges between nail points. A photograph showing a measurement of the amount of bowing caused by the water introduced behind the siding is presented in Figure 11. The exact same phenomenon was observed in the field where gypsum sheathing and gypsum board had been wetted from the bottom due to rain splashback or ponding. Unfortunately, no check for such bowing and swelling was made after the gypsum sheathing test.

These test results easily explain why swelling was noted in the bottom few feet of the siding in the field, especially in the breezeway and other areas where ponding occurred on the concrete paving. It would be unlikely (although possible) that water would pond and be wicked up into the gypsum materials for much longer than a week or two in that California climate.

Comparison Test of Effect of Water Leakage into Walls with Different Siding Types on OSB Sheathing and the Siding Materials

At the end of about one month into the test run, the moisture pins in the OSB sheathing in the four test walls were checked. It was noted that the OSB sheathing had a normal dry

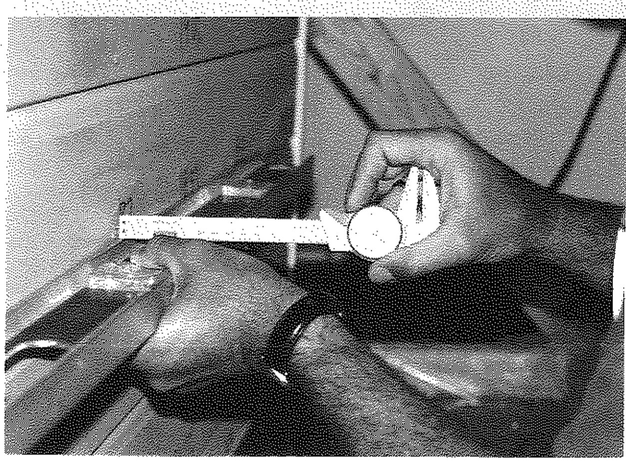

Figure 11 *Measurement of bowing between nailheads in gypsum board wicking test.*

moisture content of about 6% to 8% in both the walls with hardboard siding and the cement siding. However, the sheathing in the walls with the T1-11 plywood siding and OSB siding was above 30% moisture content and thus notably wet and potentially susceptible to decay. That trend continued until the end of the test. At the end of the four-month test, the OSB sheathing in the hardboard and cement siding walls was still dry (6% to 7% for the hardboard wall and 6% to 13% for the cement wall) except right in the vicinity where the water was introduced (7% to 10% for the hardboard wall and 9% to 12% for the cement wall). However, the bulk of the OSB sheathing in the plywood and OSB siding walls was exceedingly wet (over 40% moisture content). This was determined both by using the moisture pins and also by removing the poly and the insulation and exposing the OSB and then surveying its moisture content with an electric resistance pin-type moisture meter.

After removing the poly and the insulation batts in each wall, it was noted that the OSB was clean and largely unstained in the walls with hardboard and cement siding. However, the OSB sheathing in the walls with the plywood and OSB siding was badly stained and darkened and extremely moldy—so much so that the fiberglass insulation batt was stuck to the sheathing and difficult to remove. A photograph of the moldy and wet condition of the OSB sheathing in the wall with T1-11 siding is shown in Figure 12 as an example. The wall with OSB siding had nearly identical deterioration. Such conditions would clearly have been conducive to decay, as was noted in the field where there were leaks into the wall cavity. Given the results of these tests wherein there was little wetting of the OSB sheathing in the wall with hardboard siding, the decay found in the field could only have occurred as the result of significant amounts of water entering the wall cavities as a result of leaks. The degree of wetting in the field certainly led one to believe that the walls were indeed exceedingly wet. The lack of decay in the four-week laboratory tests also indicates that it would take a long period of very wet conditions for decay to occur.

Furthermore, after about one month of testing there was noticeable swelling of the plywood and OSB siding around the nail heads, whereas there was no noticeable degradation of the hardboard or cement siding. By the end of the four-month test, there was even more swelling of the plywood and OSB siding, with dark stains running down the outside of the OSB siding from some of the nail holes. There also was considerable yellowish staining of the outside of the cement siding, but no other deterioration. At the end of the four-month wetting test, the hardboard had some very slight swelling that was hardly noticeable around two of the nail heads directly outside the area at the top center of the wall where the drip water was introduced. There was no other swelling or other indications of moisture deterioration noted.

It would appear that the wax and resin in the hardboard minimized the absorption of water that leaked in between the siding and the building paper so that most of the water simply

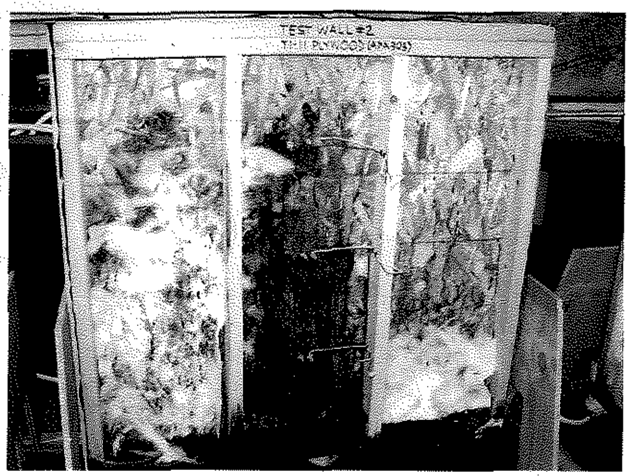

Figure 12 Moldy and wet OSB sheathing in test wall with T1-11 plywood siding.

drained out of the wall with only a minimal effect on the OSB sheathing or the siding itself. That is likely why the hardboard and OSB sheathing stayed so dry in that wall. On the other hand, it is believed that the plywood and OSB siding readily absorbed more of the drip water and thus transmitted it to the OSB sheathing, resulting in its moisture content rising well above the fiber saturation point. The cement siding is quite absorptive, but it was the only siding of the four that was lap type. That meant that there was only minimal contact with the building paper, and, hence, the OSB sheathing stayed dry. In fact, it appears that most of the water simply ran out between the siding laps near the top of the wall and did not even contact the building paper. It was observed that there was considerable water leaking out from between the laps during the drip period with consequent staining on the outside of the siding.

It has been suggested that all walls have some amount of water intrusion of one sort or another but that the building paper should act as a drainage plane so that no damage should occur to the wall. With siding materials that lay flat against the building paper, there really is limited drainage down the building paper. Some of the water that leaks in typically leaks out the joints in between the laps or the individual siding pieces, while some drains out the bottom of the wall cavity. Furthermore, some of the water wicks through the permeable building paper. A good portion of the water that leaks into the wall cavity is absorbed by the construction materials and stays there until warm, dry weather allows it to dry out. Obviously, small amounts may enter and eventually dry out in warm weather without any damage to the wall system—independent of whether the building paper acts as a drainage plane or not. However, if large amounts of water leak into the wall, a large portion of that water is absorbed by the materials in the wall, which do not readily dry out, and then deterioration can and does occur.

Water Absorption Soak Test

Each of the materials was submersed in water and then weighed each day for 14 days to determine their weight gain. The resultant percentage weight gain per square foot of exposed unpainted surface area is presented in Figure 13. It is seen that the hardboard siding is the least absorptive of all the materials tested. Both the cement and the redwood siding are more absorptive, especially during the first day or two. The percentage weight gain of the cellulose-reinforced cement siding was almost identical to results of earlier soak tests of the same type material (Cunningham et al. 1990). The most absorptive material is the pine trim, being about four times more absorptive than hardboard siding.

DISCUSSION OF RESULTS AND CONCLUSIONS

A legal case involving a San Francisco Bay area apartment complex with approximately 400 units with decay of hardboard shiplap siding and associated wood trim members, as well as OSB sheathing and other wood members, has been discussed. It has been shown that the decay was caused mainly by leakage of large amounts of rainwater behind the siding, as well as a number of poor installation practices. The main cause of the leakage was poor flashing detailing, although there were many different ways that water got behind the siding. One of the main rainwater entry points was through faulty flashing where second- and third-story concrete-topped entry walkways intersected the walls. Extensive decay below such entry points occurred repeatedly. Other siding deterioration, typically in the form of swollen siding, also was exhibited well away from the point sources behind the siding. That was alleged to be due to wicking of rainwater up between the siding laps. However, we speculated that water from the point source might move laterally behind the siding quite a way and cause the deterioration. We also noted swelling of the bottom two feet or so of the hardboard siding in some locations where there was little or no vertical clearance between the bottom edge of the siding and concrete paving. We speculated that standing water in those walkways might be wicking up improperly flashed and exposed gypsum sheathing behind the siding and causing the siding to be wetted and thus deteriorated. We also were aware of allegations that hardboard siding was a particularly bad siding material that uniquely soaked up water like a sponge if it got wet from behind and consequently could damage the OSB sheathing. Finally, there were assertions that hardboard siding is not a satisfactory siding material because of poor moisture performance.

There has been a general lack of scientifically rigorous tests to back up many of the allegations of poor hardboard siding moisture performance. So we decided to test the validity of the various hypotheses by undertaking a series of controlled laboratory tests of water migration in mockup walls with hardboard siding. Tests run on three walls with hardboard

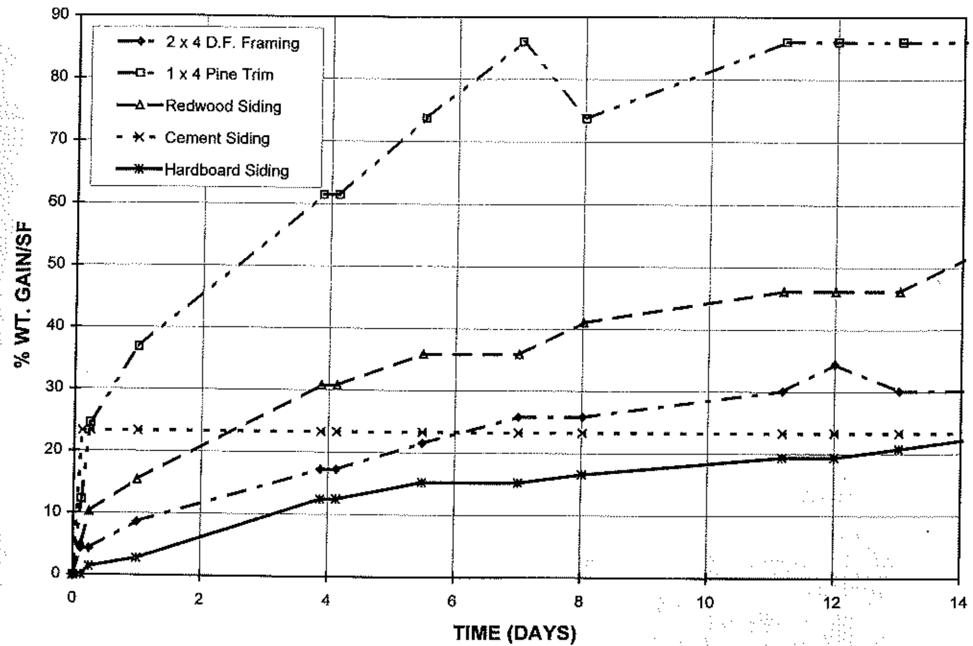

Figure 13 *Comparative soak test results of hardboard siding with other wood products.*

and redwood siding conclusively showed that water introduced at a point leak source in between the siding and the 15 lb building paper could readily migrate horizontally behind the siding for long distances. For one test wall with hardboard siding, the water flowed laterally at an angle of as little as 14 degrees from horizontal. The conclusion is that swollen siding horizontally well removed from a point leak source could readily be caused by the lateral migration of the water behind the siding. That is a new finding that correlates well with the field observations.

Another important finding from these laboratory tests is that the existence of relatively large amounts of water behind the siding for just a few weeks duration resulted in micro-cracking or checking of the paint on the bottom edges of lap joints, along with swelling of the siding around nail heads. That swelling was accompanied by bowing of the siding between nail heads. It is interesting that deteriorated siding in the field exhibited just those same characteristics. It has been suggested by some experts that all hardboard siding readily absorbs water (either in vapor or liquid form), then expands slightly, and then micro-cracks, which leads to a worsening of the situation and to ultimate failure of the siding. It appears from these tests that the swelling and micro-cracking are not characteristics of properly installed hardboard siding. Rather, it is a characteristic indication that way too much water has gotten behind the siding as a result of some type of leak. The tests also indicate that it takes more than just small amounts of water to cause these problems. Further tests undertaken for this study indicate that when similarly large amounts of water get behind T1-11 plywood or OSB siding, the same characteristics and deterioration occur to those siding materials, only the damage is much more severe and it occurs much more quickly.

Thus, the allegations suggesting that all hardboard siding performs poorly from a moisture point of view and will ultimately fail also appear to be false. For one thing, there is a great deal of hardboard siding in the field that is performing very well. That certainly is our collective experience based on years of inspecting hardboard siding in legal cases. Furthermore, one of the authors has seen hardboard siding on a large number of homes that were 20 to 25 years old and were in excellent condition, while another one of the authors has seen hardboard that is 33 years old in excellent condition on 13 fourplexes.

A second test involved spraying water on two test walls to check for the existence of rainwater wicking up between the siding laps. The amount of water sprayed was considered a worst-case amount of rainwater to fall on a wall. There was absolutely no evidence of wicking occurring in these tests. That finding is in complete agreement with other laboratory tests described in the paper as well as field observations from hundreds of dwellings where siding has been removed and inspected for signs of wicking between laps. While water staining on the backside of hardboard siding might suggest that wicking does occur, these tests show that wicking does not occur; the lateral migration tests provide an explanation for the existence of the very small amount of staining observed in the field. Almost all of the siding we have observed when removed in the field in dozens of legal cases has no staining on its backside. To the authors' knowledge, there is no scientifically verified evidence that wicking ever occurs between the laps of hardboard siding and causes damage. Allegations of wicking happening with consequent damage occurring appear to be mere speculation that lacks a factual basis.

A third set of tests involved determining the rate and vertical extent of, as well as the effect of, capillary wicking up either gypsum sheathing or gypsum board whose bottom edge was submerged in water, as occurred in the field due to ponding of water on concrete paving combined with improper flashing to protect the gypsum materials. It was found that both materials readily and quickly wicked up water from their bottom edges. In fact, water wicked up as much as about 4 ft (1.2 m) in the gypsum materials, with the gypsum board wicking faster than the more water-resistant gypsum sheathing. That led to the wetting of the OSB sheathing and hardboard siding in the test walls. The OSB sheathing in direct contact with the wetted gypsum materials was above its fiber saturation level of 25% moisture content, and so it would be prone to decay if it stayed wet. Furthermore, at the end of the tests we actually noted swelling and slight bowing of the hardboard siding that mimicked conditions noted in the field. So these results clearly explain the cause of the swelling of hardboard and the deterioration of OSB sheathing noted in the field where ponding was known to exist or where the gypsum sheathing was exposed to rain splashback. By comparison, hardboard was found to wick extremely slowly; it took four weeks to vertically wick up only 2.5 in. (6.4 cm).

The fourth set of tests involved introducing water between the siding and building paper in four walls with different types of siding and comparing the impact on the OSB sheathing and the siding materials during a four-month test period. It was found that the OSB sheathing was adversely impacted the most in the walls with T1-11 plywood and OSB panel siding (the sheathing was quite wet and moldy in both walls), whereas there was essentially no impact on the sheathing in walls with either shiplap hardboard or cellulose-reinforced cement lap siding. It is believed that the large amount of wax and resin in the hardboard kept it from absorbing as much water as the plywood and OSB siding. That allowed the hardboard to more readily drain and keep the wall the driest. Furthermore, at the end of the test, the T1-11 plywood and OSB panel siding were swollen and deteriorated, whereas the hardboard and cement siding were not. Thus, these tests showed that if water does get into a wall, then the best siding to have on the wall of those tested is either the hardboard or the cement siding. The hardboard certainly did not absorb water "like a sponge" as alleged; it remained quite dry. These tests also verified that it takes abnormally large amounts of water leaking into a wall cavity to result in swollen or deteriorated hardboard siding.

A final set of tests was undertaken to compare the relative water absorption of hardboard siding with that of other building materials, including cement siding, redwood siding, pine trim, and Douglas fir stud framing material. All these materials were soaked in a water bath for a two-week period to determine their percentage weight gain per unit surface area. The results of these tests showed that hardboard siding was the least absorptive of the materials tested. So it clearly does not soak up like a sponge in comparison to other commonly used wall materials.

In summary, a number of laboratory tests have been completed to test a number of allegations of poor moisture performance of hardboard siding. In every case, the allegations have been shown to be incorrect and without basis. The tests also clearly point out that the deterioration of hardboard siding has to do with faulty installation rather than some inherent defect in the hardboard material itself. Thus, these tests strongly suggest that hardboard siding will perform satisfactorily as long as it is properly installed and maintained. That is in complete agreement with our collective experience in dealing with many legal cases over the last 15 years where the performance of hardboard siding has been in question.

RECOMMENDATIONS

The moisture performance of hardboard siding has increasingly been questioned, in part as a result of widespread and highly publicized stories of the poor performance of other composite wood products such as OSB siding. In addition, there have been far too few field or laboratory tests of the moisture performance of walls with hardboard siding published in the open literature to counter claims of poor performance. Thus, a large number of unsubstantiated allegations of poor performance have proliferated and have even become quite believable to those without considerable field experience because they have been repeated so often. What is needed is a set of laboratory and field tests that would provide scientifically objective answers to questions regarding the possible poor performance of walls sided with hardboard. We suggest the following laboratory tests be undertaken:

1. Repeat the tests described in this paper on hardboard siding with different lap and profile designs. Such siding materials should include a lap design wherein the bulk of the back of the siding does not touch the building paper (a non-shiplap lap design).
2. Field tests of the value of back priming hardboard siding have been completed on walls that do not leak. Undertake a new four-month laboratory test of walls sided with hardboard with and without back priming wherein water is introduced in between the siding and the building paper.
3. Repeat the lateral migration tests and the siding comparison tests undertaken in this study, as well as the tests outlined in #1 and #2 above, with a spin-bonded polyolefin moisture barrier and with a grade D building paper rather than 15 lb building paper.
4. Complete a long-term laboratory spray test on walls that compares the moisture performance of lap-type hardboard siding with and without exterior paint on the lap drip edges.
5. Complete a laboratory spray test on walls to determine the influence of proper and improper nailing on buckling and

bowing of siding (testing walls with and without nailing that follows the application instructions).

6. It has been asserted that humidity changes alone will cause hardboard to permanently swell. Monitor the thickness of hardboard siding over long time periods (minimum of a year or two) under varying relative humidity conditions to assess the amount of permanent swell after the hardboard returns to a relatively dry state.
7. Repeat the four siding type tests with cedar or redwood siding and compare with the moisture performance of a wall sided with hardboard.

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