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Durability of Hardboard Lap Siding

Determination of Performance Criteria

Charles Carll
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Abstract

This report describes a study in which a current U.S. industry quality assurance test for hardboard siding was evaluated as a predictor of siding performance in accelerated exterior exposure. Additional laboratory test procedures were also performed. The study included all commercially available hardboard sidings manufactured in the United States at time of study inception, as well as siding that was specifically produced for this study at one manufacturing plant. The siding was installed on outdoor fences that were sprayed with water for 1 hour every day during the summer. We periodically monitored siding performance over 38 months of exposure. Performance of commercially available boards varied appreciably, both in laboratory testing and on the test fences. However, there was some consistency in the types of performance problems that were exhibited. The "weatherability of substrate" test procedure contained in the American National Standard proved to be an imperfect, but nevertheless useful, predictor of some performance characteristics on the test fences. The data suggest that the current criterion in the standard (20% maximum residual thickness swell) does exclude boards prone to serious performance problems but that the incidence of such problems may be significantly reduced by lowering the maximum allowable level to 17% or lower.

A painted drip edge significantly retarded development of performance problems. Water stains on the back surfaces of siding provided no convincing evidence of significant vertical capillary rise of water at siding laps but nevertheless suggested that back surface wetting and liquid water retention in the laps played a role in siding degradation. Sorption and desorption isotherms, representing equilibrium moisture content at various ambient relative humidities, are also presented in this report.

Keywords: moisture, durability, hardboard siding, thickness swell, edge welt, mildew, vapor sorption, paint cracks, moisture content, staining

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Summary

This report describes results of a study on durability of hardboard siding. The objectives of this study were (1) to examine the extent to which performance in the current industry standard test procedures for "weatherability of substrate" correlates with siding performance in use, (2) to determine if changes in the acceptance criterion for "substrate weatherability" are justified, and (3) to examine to what degree results from other laboratory tests correlate with siding performance in use. The results cover outdoor exposure of hardboard siding on water-sprayed test fences over the period July 1997 to October 2000, as well as the results of several types of laboratory tests.

We observed the following in laboratory testing:

- Residual thickness swell (RTS) and 24-h edge water absorption test results varied considerably among commercial hardboards.
- Most of the commercial hardboard siding tested met the industry criterion of 20% maximum RTS. However, 14% of tested specimens from one of the classes of commercial hardboard exceeded 20% RTS.

We observed the following on water-sprayed test fences:

- The most noticeable failure mode was surface welting, which occurred earlier and to a greater extent near drip edges (in lap areas) than it did on board end cuts. The next most noticeable failure modes were (1) paint film breakage on drip edges and (2) board swelling that resulted either in cracks in the paint film at the nail heads or in "dimpling" around nail heads.
- There was no noticeable buckling, but test specimen size and attachment to fences was such that noticeable buckling would have been unlikely.
- No visible evidence of decay appeared in any of the siding. Open end joints at board ends evidently permitted water entry but also provided drainage and drying.
- Minor amounts of mildew appeared on the painted surfaces of some boards. The exposure regimen (appreciable sun exposure, daily spraying with quantities of water sufficient to flush the board surfaces), however, may not have been conducive to mildew growth.
- Paint performance was generally good, even on the test fence where drip edges had been removed.
- There were substantial differences in performance of commercial boards, especially with regard to edge welting.
- A painted drip edge substantially retarded development of surface welting at the drip edge, reduced the magnitude of measured in-service swelling, and also reduced development of paint cracks at nail heads.

Correlations between laboratory RTS data and performance on the fences showed the following:

- Direct correlations of RTS and any given measurement of field performance were rarely strong. There was usually substantial scatter in the data, but RTS nevertheless often was a useful indicator of field performance.
- RTS proved to be a good indicator of the likelihood of edge welting. The data suggest that lowering the test criterion in AHA/ANSI Standard A135.6 to 16% or 17% would noticeably reduce the incidence of edge welting in service and that lowering it still further would have additional benefits.
- RTS proved to be a reasonably good indicator of the likelihood of mildew growth on painted surfaces. The data suggest that lowering the RTS criterion in the standard to 16% or 17% is likely to reduce the incidence of mildew growth in service but do not suggest that further reductions would be beneficial.
- RTS proved to be a good indicator of the likelihood of paint cracking on drip edges. The data suggest that lowering the RTS criterion in the standard to 18% would noticeably lower the incidence of drip edge paint cracking and that further reductions would yield additional benefits.

Our review of the ANSI/AHA Standard A135.6 for hardboard siding led us to two conclusions:

- The standard in its current form lacks an appropriate statistical basis for sample selection.
- The standard does not account for the effects of variability in the test results.

Other conclusions and observations included the following:

- The degree of back-surface water staining varied appreciably between commercial hardboards. Despite significant water staining on the back surface of some boards, there is no convincing evidence that vertical capillary suction in the laps between boards played a significant role in back-surface wetting. With the short specimen length and open end joints, migration of water from board ends appeared to play a substantial role in back-surface wetting. However, retention of water in lap areas may be an important factor in board degradation.
- Considerable mold growth occurred on specimens exposed to 97% relative humidity (RH) during the sorption tests, but there was no visible mold on any of the specimens maintained at 79% RH.

Based on the conclusions and observations, we recommend that ANSI/AHA Standard A135.6 be revised to include statistically based criteria for sample selection and that statistically based criteria be included to account for variability in the measurements. The report contains a specific suggestion for determination of sample size. We also recommend that the RTS pass–fail criterion in the standard be lowered to 17% or lower, which likely will decrease in-service edge welt and drip-edge paint cracking and potentially reduce the chance of mildew growth. Although there likely would be additional performance benefits from lowering the criterion further, the authors believe that such a decision should also be based on factors such as the effect on mill operation and economics, which are outside the scope of this report.

Contents

Durability of Hardboard Lap Siding
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Background

Although failure of hardboard siding often occurs due to improper installation or detailing (Keplinger and Waldman 1988, HUD 1992), more stringent test requirements than stated in industry standard ANSI/AHA A135.6-1998 (AHA 1998) might reasonably lead to improved performance and durability of hardboard siding in service. The literature to date does not include evidence that the current minimum test requirements correlate with satisfactory performance in service.

Accelerated aging tests have long been used as a method to screen products for durability, but it is difficult to correlate results of accelerated exposure with exposure to natural weathering (Ruffin 1960). The hardboard industry currently uses a number of tests (ANSI/AHA A135.6-1998) to evaluate hardboard siding and has formulated minimum test criteria. Keplinger and Waldman (1988) and Baldwin (1988) suggest that when there are durability problems with hardboard siding, irreversible (or "residual") thickness swell is frequently a contributing factor to or a cause of problems. We therefore postulated that results from the ANSI/AHA A135.6 test procedure for "weatherability of substrate" would be a reasonably good predictor of durability in service. This procedure prescribes six consecutive cycles of wetting, drying, and freezing of the hardboard and requires the measurement of the permanent increase in the thickness of the drip edge (residual thickness swell, or RTS). ANSI/AHA A135.6-1998 allows a maximum RTS of 20%. Published measured values for commercial hardboard siding vary between 2% and 17% (Biblis 1989, 1991). The degree of residual swell of individual products primarily depends on chemical additives or heat treatments, raw materials, prevention of buildup or relief of residual stresses during manufacturing, amount of adhesives used, or sizing additives (Carll 1996).

Permanent thickness swelling in response to consecutive wetting and drying cycles is one important way in which wood composition materials distinguish themselves from solid wood. Wood swells when wetted and returns to virtually its original thickness when dried. Wood composition materials, on the other hand, because of inter-leaving of the wood elements (particles, flakes, or fibers) in the mat prior to pressing and because of compaction under high pressure during pressing, contain internal residual stresses that may relax during wetting–drying cycles. Hardboard siding generally shows less RTS than other commercial wood composition materials bonded with similar adhesive systems, in particular those made from wood particles or flakes (River 1994). However, hardboard siding can exhibit significant levels of RTS (Biblis 1989, 1991, River 1994). If swelling is extreme, paint may crack, caulking may fail, and nail heads may be pulled through the paint surface, providing pathways for water entry into the board. Although no published evidence directly links residual swell and siding degradation, Kelly and others (1984) showed that hardboard siding with appreciable residual swelling can absorb water much more easily than hardboard with small amounts of residual swelling.

Table 2 of the Canadian standard CAN/CGSB-11.3-M87 for exterior hardboard specifies a limit of 15% allowable RTS after exposure to cyclic accelerated aging (Canadian General Standards Board 1987). The Canadian standard prescribes full immersion of the sample in hot water, with subsequent exposure to 200°F steam, and follows procedures described in ASTM Standard D 1037 (ASTM 1995a). The ANSI/AHA weatherability of substrate procedure, in contrast, calls for soaking of one sample edge only and does not include a steam cycle. The literature suggests that edge soaking is better able to identify boards with appreciable levels of water absorptivity than is a full immersion test (Kelly and others 1984, Biblis 1989). Kelly and others (1984) saw greater water absorption in edge soak exposures than in full immersion tests. Biblis (1989) found that RTS as determined with the ANSI/AHA substrate weatherability test usually exceeded RTS after full immersion testing. Differences between boards that were not detectable by full immersion testing could be identified by the ANSI/AHA substrate weatherability test. Although the literature suggests that it would be a better predictor of in-service siding performance than other test procedures, the literature to date does not include evidence that the ANSI/AHA procedure correlates with natural or accelerated outdoor exposure or with satisfactory performance in service.

Various researchers have identified correlations between mechanical property values of wood composites after laboratory test procedures and after natural weathering of small unpainted specimens placed in outdoor exposure with all surfaces of the boards exposed to the weather (River 1994, Beech and others 1974, Dinwoodie 1981). River (1994) found reasonably good correlations for mechanical properties between laboratory test procedures and outdoor exposure for various outdoor exposure periods. When thickness swelling was the measurement criterion, River (1994) found that the correlation between laboratory test results and field performance was generally weaker than that for mechanical properties and that the correlation depended on exposure period. His findings were complicated by the fact that some boards underwent appreciable in-field swelling during the initial years of exposure but then decreased in thickness due to the loss of surface flakes or fibers from their unpainted faces. Our study employed natural outdoor exposure and accelerated outdoor exposure of hardboard siding, with test specimens primed and painted and in contact with sheathing, in an attempt to realistically simulate installation on a building. Furthermore, we evaluated physical behaviors that are indicative of siding performance.

Objectives

The objectives of this study were to (1) examine to what extent performance in the current industry standard test procedures for "weatherability of substrate" correlates with siding performance in use, (2) determine if changes in the acceptance criterion for "substrate weatherability" are justified, and (3) examine to what degree results from other laboratory tests correlate with siding performance in use.

Approach and Methodology

The basic premise of this study was that siding durability is to some extent related to moisture absorption properties. Although siding can degrade for a variety of reasons, it is logical that siding with low hygroscopicity and liquid absorptivity would provide better performance when paint application procedures are imperfect, caulk seals fail, or maintenance is less than ideal. In addition, a siding that exhibits little thickness swell in response to water uptake would reasonably be expected to develop less cracking of paint coating or problems with nail heads breaking the paint surface. We hypothesized, therefore, that laboratory tests that assess the moisture absorption and thickness swell of hardboard siding could be useful tools in predicting the durability of hardboard siding in the field.

We conducted a series of laboratory and field exposure tests on a variety of hardboard sidings and correlated the observations from field exposure tests with the results of laboratory tests. The materials were obtained from various sources and showed wide ranges of residual thickness swell (RTS) and liquid water absorptivity. Siding specimens were installed on a test building (exterior exposure without additional water spray) and on two test fences that were sprayed with water for 1 h once a day during the summer (accelerated exterior exposure). We conducted regular extensive inspections of the exposed siding.

Materials and Specimen Selection

The materials in this study included seven commercial hardboard sidings, one OSB siding, and six non-commercial hardboard sidings, which we selected from different batches of boards that were specially produced for this study. All U.S. hardboard manufacturing plants producing hardboard siding in 1996–1997 were represented in this study. The Forest Products Laboratory (FPL) did not retain any information on the origin of the commercial boards.

Non-Commercial Siding

Georgia Pacific Corporation produced dry-process hardboard siding specifically for this study at lower than usual steam pressures and shorter press times, to provide FPL with test materials exhibiting a wide range in properties. This material was produced in three separate lots. Some board was also produced at normal temperatures and press times. These boards were shipped to FPL unprimed and unpainted in 4- by 8-ft (1.2- by 2.4-m) sheets. At FPL the sheets were sawn into 8-ft (2.4-m) by 8-in.- (0.2-m-) wide strips of lap siding; these siding strips therefore did not have shaped drip edges. Strips from the separate lots were kept segregated and were marked as cut to retain a record of the sheet and position within the sheet from which they were cut.

After preliminary tests of RTS, we found that the strips of non-commercial board could provide six separate classes of lap siding. The six classes were determined by lot and by position within the sheet (see Table 1 and Fig. 1).

Table 1—Class designations for non-commercial siding

Class	Average RTS[a] (%)	Notes[b]
1	5.9	Produced with normal temperatures and press time
2	6.7	Lot 1, strips 2 through 5
3	8.9	Lot 2, strips 2 through 5; Lot 3, strips 3 and 4
4	12.0	Lot 3, strips 2 and 5
5	22.7	Lot 2, strips 1 and 6 (edge strips)
6	30.1	Lot 3, strips 1 and 6 (edge strips)

[a]Residual thickness swell, average of 80 samples, ANSI/AHA A135.6.
[b]Strip designation numbers refer to their location in the sheet corresponding to Figure 1.

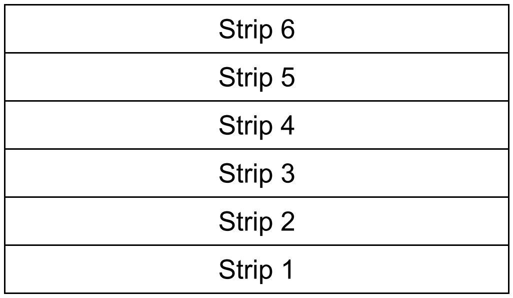

Figure 1—Strip designation numbers and their location in the sheet.

Of the non-commercial siding, class 1 had the lowest RTS. The RTS of the other material varied widely with location in the sheet, with strips from sheet edges showing the highest RTS. Classes 2, 3, and 4 were therefore selected from the center of the sheets, producing low to medium values for RTS. Classes 5 and 6 were cut from the edge of the sheet, and the average RTS of this material did not meet the industry minimum standard of 20%.

Commercial Siding

The seven commercial hardboards were cut from 4- by 16-ft (1.2- by 4.9-m) master sheets at the producing mills using the identification scheme shown in Figure 2. The lap siding delivered to FPL was 8 ft (2.4 m) long and nominal 8 in. (0.2 m) wide. All commercial hardboard was factory primed and had beveled or slightly rounded drip edge, which had been "preformed" prior to priming. Because OSB siding was available only in 4- by 8-ft (1.2- by 2.4-m) panels, the siding was cut from these panels at FPL. All board had flat, smooth (not textured) front surfaces except the OSB, which had a textured face. OSB siding contained zinc borate, which was confirmed by atomic emission spectroscopy.

Commercial boards from each mill were randomly assigned a class number (classes 7 to 14). Unlike class numbers 1 to 6, which reflect relative performance in the substrate weatherability test procedure, class numbers for commercial boards are not indicative of any performance ranking. Boards in class 12 contained press blows, but these defects were so inconspicuous that we did not notice them until we observed unusual on-fence behavior of these boards.

Specimen Selection

Twenty boards from each board class (a total of 280 boards) were selected to provide specimens. Each board yielded three specimens for outdoor exposure tests, four specimens for weatherability of substrate (residual thickness swell) tests, and one specimen for the water absorption test (Fig. 3). Specimens for vapor sorption tests were cut from the interior edge of the end pieces.

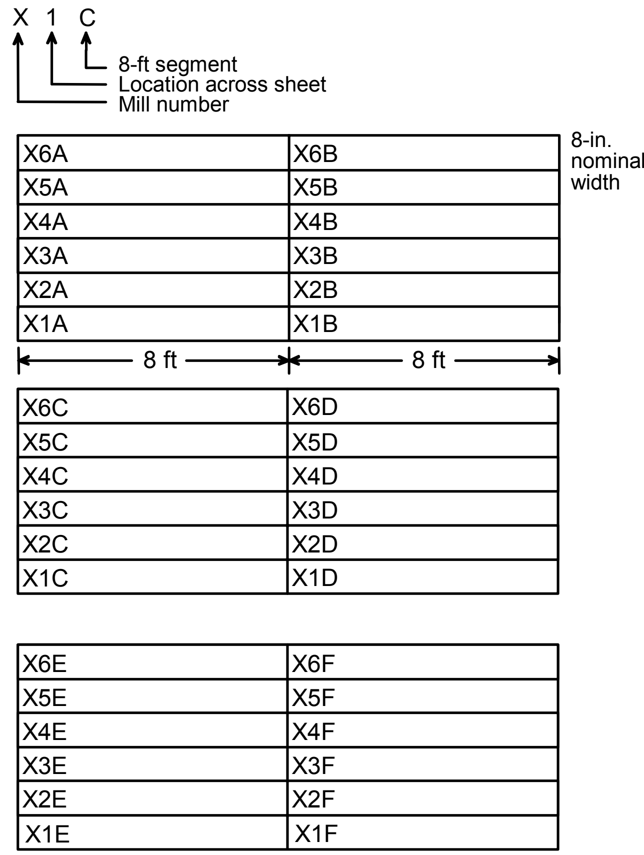

Figure 2—Diagram for cutting and identifying commercial hardboard lap siding from master sheets.

Specimens for exterior exposure were brush-painted with two thin coats of satin exterior latex paint. On the commercial hardboards, the latex paint was applied over the factory primer. On the non-commercial hardboards, which were not factory-primed, the latex paint was applied over brush-applied alkyd primer.[1] The OSB siding had a resin-impregnated paper face, which is intended to serve as a topcoat base, and was painted with two coats of satin latex paint without priming. Average spread rate for the combined two coats of latex paint was 387 ft^2/gal (9.5 m^2/L) on the (smooth) hardboard and 267 ft^2/gal (6.6 m^2/L) on the OSB. All brush painting was performed in a conditioned laboratory. Specimen end-cuts were left bare.

Outdoor Exposure Tests

Test Fence Exposure

The test fences were located at the FPL Valley View test site just west of Madison, Wisconsin. Boards on the two test

[1]The alkyd primer was from the same manufacturer as the latex topcoat. It was compatible with the topcoat and recommended by the paint manufacturer for use on hardboard that had not been factory-primed.

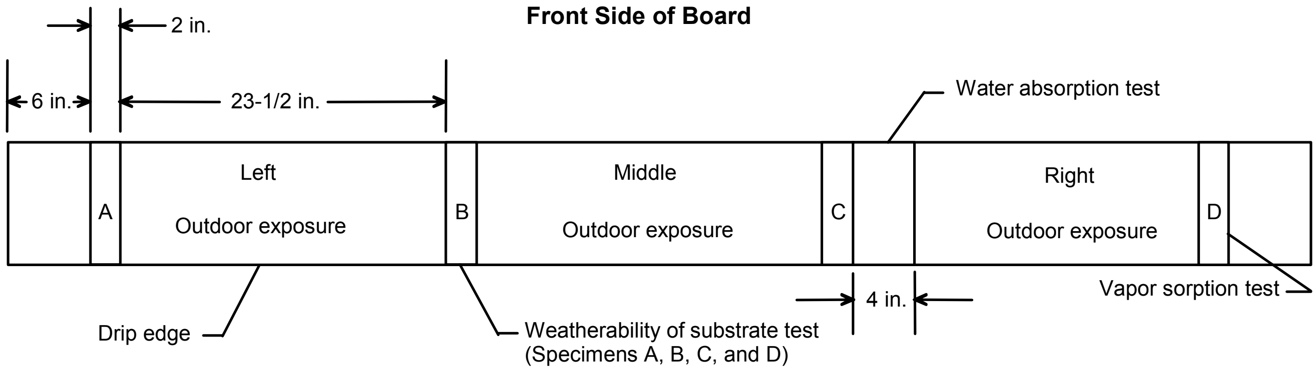

Figure 3—Diagram for cutting specimens from boards.

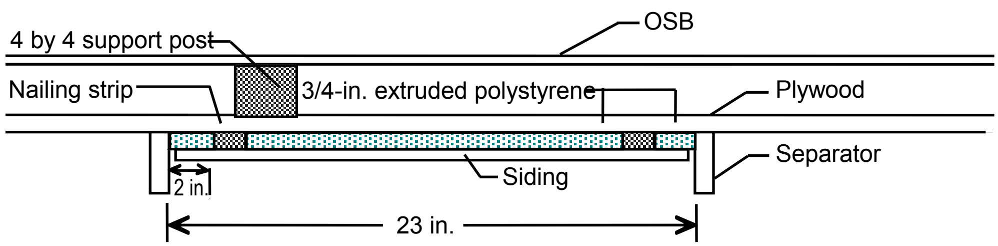

Figure 4—Diagram of test fence construction (top view).

fences faced south and were exposed to the weather and artificial wetting for 38 months. Boards were mounted on the test fences on a 0.75-in. (19-mm) thick foam sheathing to simulate exposure on an insulated wall. On each fence, boards were installed as lap-siding courses in 28 columns of 10 boards, each course with 6.625 in. (0.17 m) of exposure.

Column width (or specimen length) was 22.5 in. (0.57 m). Plastic–wood composite lumber, which was fastened to the (19 mm) plywood sheathing, separated adjacent columns. There was a gap of roughly 0.25 in. (6 mm) between each board end and the column separator (Fig. 4). These gaps simulated open (uncaulked) joints between siding and corner trim.[2] Boards were installed on the fences in July and August 1997 and removed on October 12 and 13, 2000. Figure 5 shows both test fences immediately after installation of the boards. The two fences were identical, with one exception: on fence 1, all drip edges were cut and left bare, whereas on fence 2, the painted drip edges were left intact. End cuts were left bare on both fences.

[2]Open joints are contrary to AHA application instructions; they allow water entry at board ends. The open joints remained open down past the bottom siding course, unlike an open joint or a failed caulk joint between siding and window jamb casing. The open joints past the bottom siding provided appreciable drainage potential. The appreciable width of open end gaps, coupled with the fact that the siding was true lap siding (as opposed to shiplap siding) also provided for back-face venting.

Each column of siding on the two test fences was individually sprayed for 1 h each day from May through late November. The spray was turned off during the winter. Spraying started mid-August 1997. The water spray hit above the top board and water ran down each column of siding. Column separators prevented water movement between columns. The water was drawn from a well on the test site. To verify that each column received comparable amounts of spray water, we measured the water spray rate of each spray nozzle in July 1997 and again in June 1998. We found that although the rate varied with water pressure, the average flow rate was about 0.23 gal/min (15 mL/s), with maximum variations between nozzles of about 10%. Each nozzle delivered a fan-shaped spray of water, with the long dimension of the fan oriented horizontally (Fig. 6). The spray was directed at a siding strip above the top board in each column. The spray fan could be deflected by wind but did not reach board ends, even under moderately windy conditions.

The spray nozzles therefore did not spray water directly into the open end joints, except perhaps under very windy conditions. Water ran down the face of the specimens in rivulets, which sometimes remained continuous between adjacent courses, and sometimes ended at drip edges, with water dripping off the drip edge. It was common to find rivulets across the entire width of a board specimen. Water was also commonly present on vertical end surfaces of a test specimen during spraying.

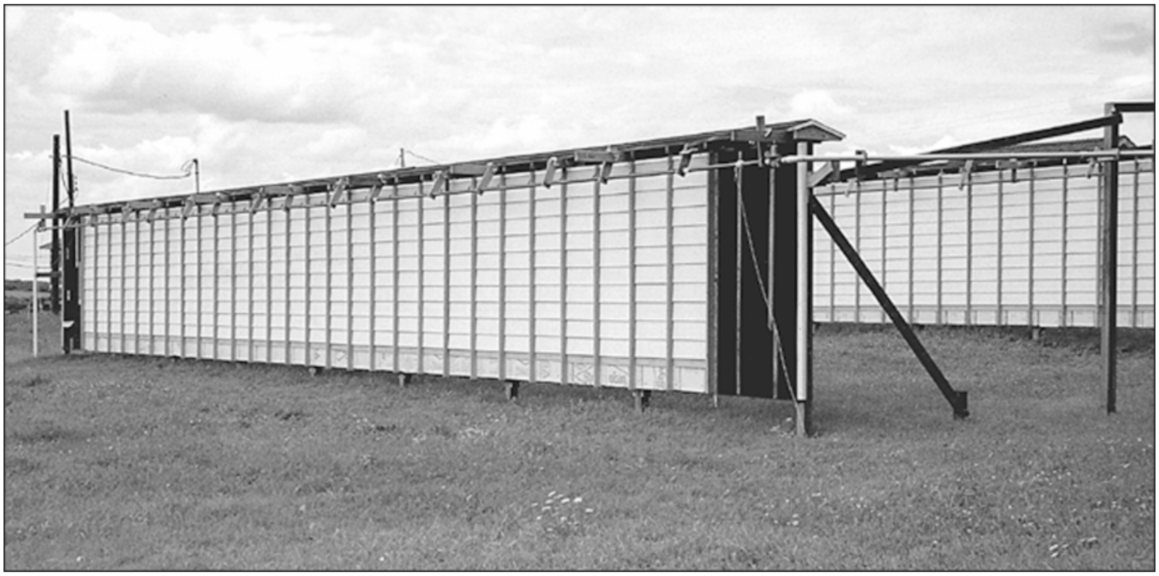

Figure 5—Test fences at the FPL Valley View test site.

Figure 6—Spraying of the fences.

Test Building Exposure

Boards also were installed on the south-facing wall of a test building near the test fences. These boards are still on the building at the time of this report; we intend to monitor this siding until September 2007, for a total of 10 years. The wall is exposed to the weather but is not sprayed with water. The boards were treated the same as for fence 2 (that is, drip edges were left intact and painted, but cross cuts were left bare). The boards were cut to a length of 17.75 in. (0.45 m). Each column was separated from adjacent columns by vertical column separators made of treated lumber. The open (uncaulked) joints between siding ends and column separators were similar to those on the test fences.

Specimen Placement

Specimen placement was identical on the two test fences and the building. The 20 boards of each of the 14 classes were placed randomly over the 28 columns. However, because the water was sprayed at the top of the wall, we felt it appropriate that all 14 classes be represented equally in the top four positions. Thus, separate randomization was applied to the top four courses and the rest of the courses. Eight boards of each class were placed in the top four positions on each of the fences and the wall, and the remaining 12 on the middle and lower sections.

Inspections

During the period of May to November, two or three full inspections were made each year, always by the same person. The inspection protocol evolved over time, but it was consistent between inspection dates by November 1998. Each board was inspected for surface discoloration of the painted face by mildew, evidence of decay, edge welt, and paint condition. We did not attempt to immediately identify mildew species as mildew was found, although an FPL mycologist identified mildew species on a few board specimens after the final inspection. We also checked for breaks in the paint surface at each nail head, which could provide a path for water entry.

The first inspection took place in late September 1997. The last inspection of the siding on the test fences occurred between September 26 and October 4, 2000, with siding removal from the fences following shortly thereafter on October 12 and 13, 2000. Siding on the building continues to be inspected at yearly intervals.

In-Place Thickness Measurements

In-place thickness was measured at approximately the same time as inspections were made. Thickness measurements were assumed to be less subject to individual technique or perception than were other inspection observations and thus were not always performed by the same person. In-place thickness was measured in two locations on the drip edge, using the technique described by Carll and others (2000). The measurement device consisted of a dial gauge with a square stationary foot, which was placed against the bottom of the drip edge to be measured, on the siding course below (Fig. 7). The round foot on the dial gauge rested on top of the drip edge. We placed the side of the stationary square base against the column separator. This provided for consistent location of the measurements, at about 3 in. (74 mm) from each corner of the drip edge. On the building, we used a smaller square base and measured thickness at about 2 in. (50 mm) from each specimen corner, to avoid measuring on top of the nail heads.

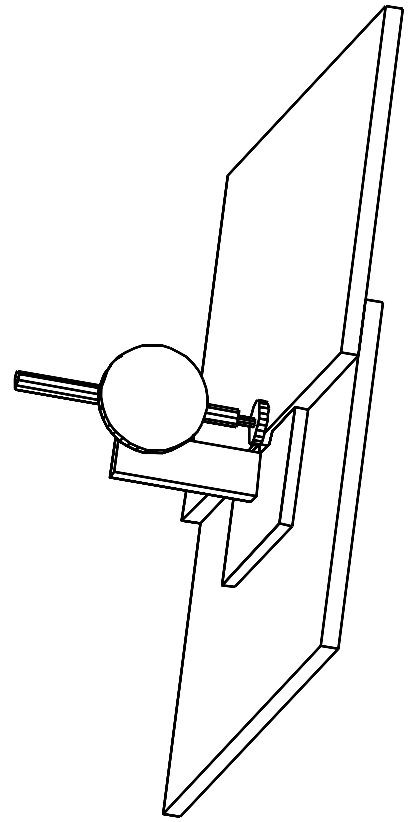

Figure 7—In-place thickness measurement device.

Measurement During and After Siding Removal

Staining on the back—We made note of staining on the back of specimens when we removed them from the test fences in October 2000. We quantified the extent of staining during a subsequent reexamination.

Moisture content at time of removal—We determined the moisture content (MC) at time of removal by weighing each board immediately after removal. We subsequently transported boards to FPL and placed them in a room maintained at about 70ºF (18ºC), 50% relative humidity (RH) for over 6 months. We then weighed the reconditioned boards. Finally, we determined the ovendry weight, allowing us to determine MC at time of removal and after re-conditioning to 50% RH, 70ºF.

Final thickness swell—We measured board thickness after reconditioning at 70ºF (18ºC), 50% RH. We determined the thickness of the drip edge near the side edges and in the middle. These results were compared with measurements made at the same locations before installation on the fence.

Laboratory Tests

Weatherability of Substrate

We performed weatherability tests on 80 samples of each siding class according to section 4.1, Weatherability of Substrate, of ANSI/AHA A135.6-1998. Each sample measured 6 by 2 in. (150 by 51 mm) with unprimed edges, and four samples were cut from each of the 20 siding boards as shown in Figure 3. The drip edge was cut off and left bare.

Specimens were first conditioned at 70°F (18°C), 50% RH, after which thickness was measured at the center of the edge to be submerged. Specimens were then exposed to six 24-h cycles, each cycle consisting of the following steps:

1. Suspension in 100°F (38°C) deionized water for 18.5 h. Specimens were suspended vertically with the bottom edge immersed to a depth of 1 in. (25 mm).
2. Placement in a 220°F (104°C) oven for 30 min.
3. Placement in a freezer at 0°F (–18°C) for 2 h. This was slightly colder than the temperature of 5°F (–14°C) specified in ANSI/AHA A135.6-1998.
4. Placement back in the oven for 30 min.

Steps 3 and 4 were repeated to complete a 24-h cycle.

Fresh deionized water was used for each cycle. After the sixth cycle, the specimens were reconditioned at 70°F (18°C), 50% RH, after which the thickness of the edge was again measured to determine the residual swell.

Edge Water Absorption

A 24-h edge water absorption test was performed on 20 specimens (4 by 8 in., 102 by 204 mm) of each type, as described by Kelly and others (1984). The specimens were suspended vertically with the bottom 1 in. (25 mm) of the board submerged in deionized water heated to 100°F (38°C). After immersion for 24 h, the bottom 4 in. (102 mm) of each specimen was cut into 16 slices approximately 1/4 in. (6 mm) wide, parallel to the submerged edge of the specimen. These slices were individually weighed and oven-dried to determine moisture content. Moisture content was recorded as a function of distance from the submerged specimen edge.

Water Vapor Sorption

We determined equilibrium moisture content, also known as water vapor sorption isotherms, using a methodology similar to that described by Richards and others (1992). For each class of siding, we selected 15 boards and cut two specimens from each board. The 15 pairs of specimens were then divided into two groups of 15 specimens each. Specimen size was approximately 2 by 1/16 in. (51 by 1.6 mm), and specimen weight ranged from 0.5 to 0.7 g. The procedure generally complied with, or exceeded, the requirements in ASTM Standard C 1498-01, Standard Test for Hygroscopic Sorption Isotherms of Building Materials (ASTM 2001), except that our samples weighed less than 10 g. The specimens were placed in jars containing saturated salt solutions at 73°F (23°C). Temperature in the room was controlled within 1°F (0.6°C). The following four salts were used:

Salt	Equilibrium RH (at 73°F, 23°C) (%)
Magnesium chloride ($MgCl_2{\cdot}6H_2O$)	33
Sodium bromide (NaBr)	58
Ammonium chloride (NH_4Cl)	79
Potassium sulfate (KSO_4)	97

Each specimen was weighed with a precision balance with an estimated reading error of 0.0002 g. Specimens were weighed immediately after removal from the jar. Weight measurements were made a minimum of 4 days apart, except for measurements performed at 97% RH. We assumed equilibrium had been reached when the weight change between two consecutive measurements was undetectable (that is, less than 0.0002 g.). This translates to an equilibrium criterion of about 0.007% of specimen weight per 24 h. This is more stringent than the weight change criterion of 1% of specimen weight over a 2-week period used by Richards and others (1992) and probably more stringent than the criterion in ASTM 1498 of 0.1% of specimen weight in five successive readings at 24-h intervals.

The specimens were first dried by placing them in jars with calcium chloride desiccant. To obtain a vapor adsorption isotherm, 15 specimens from each siding class were then placed in jars at sequentially higher humidities, up to 79% RH, and allowed to come to equilibrium at each humidity level. After reaching equilibrium at 79% RH, the specimens were weighed and placed in jars at sequentially lower humidities (58% RH, 33% RH, and desiccant) to obtain a desorption isotherm. Due to problems with mold growth at 97% RH (potassium sulfate), we followed a different procedure to obtain equilibrium data at 97% RH: A second group of 15 specimens from each siding class was directly moved from the desiccant to the 97% RH environment. To inhibit mold growth, this group of specimens was exposed to 185°F (85°C) for 2 h in the 97% RH conditioning jars. The jars were then returned to the 73°F (23°C) room, and the specimens were allowed to reach equilibrium by leaving them in the closed jars for 11 weeks or more, without intermittent removal and weighing. After weighing, they were moved to the 79% RH jars, and subsequently a desorption isotherm was obtained as with the other group of specimens.

After final exposure to the desiccant environment at the end of the cycle, specimens were oven-dried at 215°F (102°C) for 3 h to determine ovendry weight (compared with desiccant-dry weight). Because a large number of specimens were removed simultaneously from the oven and could not all be weighed immediately, it was necessary to minimize vapor adsorption of specimens between removal from the oven and weighing. A 1-in.- (25-mm-) thick aluminum plate measuring 2 by 10 in. (0.05 by 0.25 m) was placed in the oven with the specimens on top. The plate and specimens were removed from the oven and placed next to the balance. The residual heat from the plate kept the specimens close to oven temperature, minimizing vapor sorption from the ambient air until each sample was weighed.

Density and Thickness

We determined the ovendry density of 10 samples of each class of hardboard. We used the same oven-drying technique that we used for the sorption measurements.

Data Analysis

With the exception of edge water absorption, all data were recorded by sample ID to allow cross correlation between measured parameters on a sample-by-sample basis.

Results

Laboratory Tests

Weatherability of Substrate

Results of weatherability tests for the non-commercial boards are shown in Table 2. The RTS of classes 1 to 6 cover a broad range. Classes 1 and 2 exhibited very little RTS, whereas most boards in classes 5 and 6 did not meet the minimum industry standard of 20%.

The RTS results for the commercial boards (Table 3) show considerable variation between classes. On average, all classes meet the industry minimum standard, but a significant minority of the test specimens in class 8 failed to meet the standard.

The commercial OSB siding specimens (class 9) had an average RTS of 19.3% (standard deviation 3.2%), with 44% of the specimens failing the 20% criterion for hardboard. Of course, OSB siding is not required to meet the specifications in ANSI/AHA A135.6, which are specifically for hardboard siding.

Edge Water Absorption

Figure 8 shows the moisture distribution in the first 4 in. (0.1 m) of the specimens, averaged by siding class. Class 14 absorbed much more water than did any other class. Classes 10 and 12 showed the least water absorption. There does not appear to be a direct correlation between RTS and water absorption behavior.

To arrive at a single index for water absorption, we calculated average moisture content of the 16 slices and subtracted the moisture content (MC) of the top slice, which was 3 in. above the waterline during immersion. The data indicate that water did not penetrate that far up in the sample. The calculated value thus represents the increase in average MC of the first 4 in. of the specimen due to water absorption. Table 4 shows the calculated values, along with other results from the test. Class 14 boards had an average MC increase of 28.9%, over three times as much as that of the board class (class 6) with the next highest average MC increase (8.0%). When class 14 and all non-commercial boards (classes 1 to 6) are ignored, considerable variation in water absorption remains: Class 8 showed more than twice the water absorption of the two least-absorptive classes of commercial board (classes 10 and 12). A statistical analysis (Tukey multiple range test) of individual measurements indicated that individual classes or groups of classes differed from each other with respect to MC increase (Table 5).

The extremely high water absorption of class 14 boards led us to question whether wax sizing had been accidentally omitted during manufacture. The FPL analytical chemistry laboratory performed room-temperature toluene extractions on two specimens of class 14 board. As a reference, they also performed toluene extractions on two specimens of

Table 2—Weatherability of substrate, final results for non-commercial boards

Class	Average RTS (%)[a]	Standard deviation (%)	Specimens exceeding 20% RTS (%)
1	5.9	1.8	0
2	6.7	1.3	0
3	8.9	2.0	0
4	12.0	2.5	0
5	22.7	3.2	80
6	30.1	5.6	99

[a]Average residual thickness swell of 80 samples.

Table 3—Weatherability of substrate, final results for commercial boards

Class	Average RTS (%)[a]	Standard deviation (%)	Specimens exceeding 20% RTS (%)
7	11.5	1.2	0
8	15.0	4.4	14
10	4.9	1.0	0
11	7.5	2.9	0
12	9.1	3.7	0
13	12.4	1.4	0
14	11.0	2.0	0

[a]Average residual thickness swell of 80 samples.

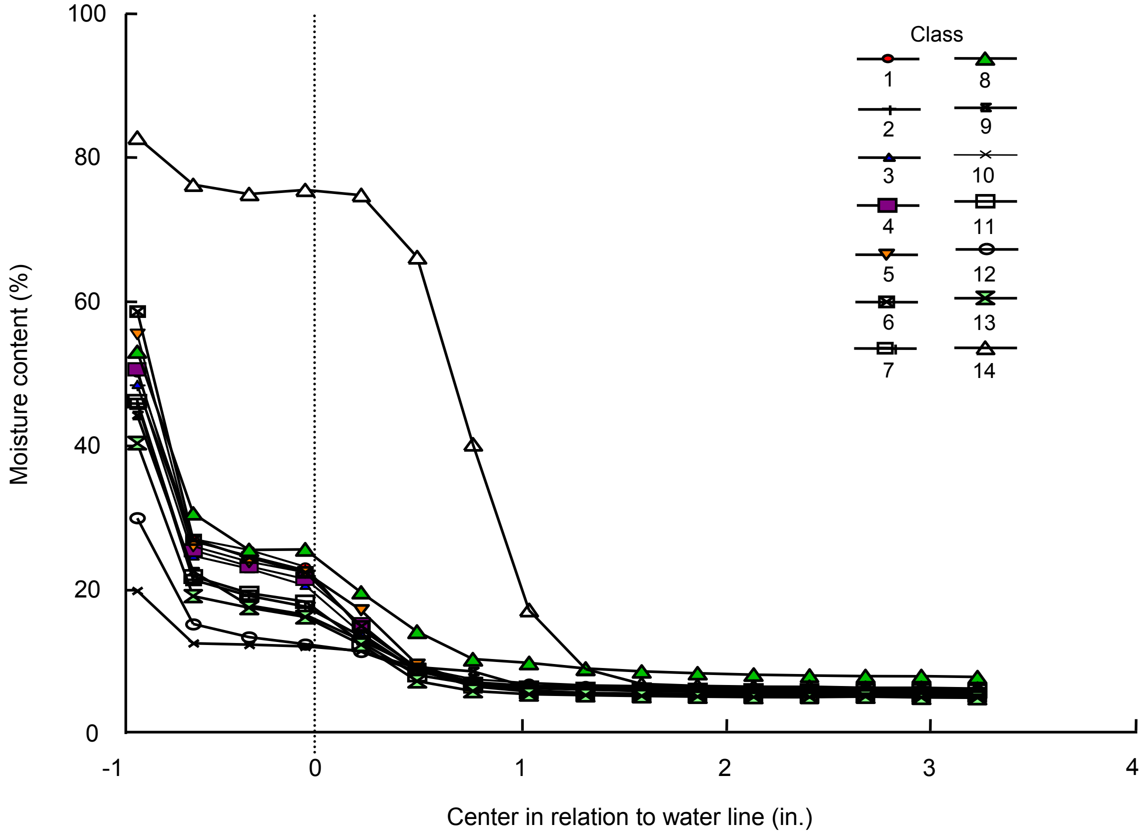

Figure 8—Average moisture distribution in bottom 4 in. of the specimens after 24-h vertical immersion.

Table 4—Results of 24-h edge water absorption tests, average of 20 specimens

Class	Maximum MC (%)	Average MC (%)	MC at 3 in. above water surface (%)	Increase in MC (%)	
				Average	Standard deviation
1	50.15	13.53	6.25	7.28	0.36
2	48.47	13.01	5.80	7.21	0.24
3	48.54	12.29	5.30	6.99	0.31
4	50.65	12.56	5.34	7.22	0.22
5	55.54	13.18	5.24	7.94	0.36
6	58.71	13.32	5.27	8.05	0.36
7	45.89	11.77	5.77	6.00	0.39
8	53.15	16.01	7.98	8.03	0.72
9[a]	44.28	11.55	5.43	6.12	1.15
10	19.90	8.85	6.05	2.80	0.20
11	46.24	11.83	5.99	5.77	0.76
12	30.01	9.54	5.69	3.85	0.57
13	40.42	10.39	5.03	5.36	0.38
14	82.82	35.21	6.34	28.87	3.89

[a]OSB siding.

Table 5—Results of Tukey multiple range testing on ranked values of individual specimen MC increase values

Class	Average increase in MC (%)	Groupings[a]			
14	28.9	A			
6	8.0		B		
8	8.0		B		
5	7.9		B		
1	7.3	C			
4	7.2	C			
2	7.2	C			
3	7.0	C	D		
9	6.1		D	E	
7	6.0			E	F
11	5.8			E	F
13	5.4				F
12	3.8	G			
10	2.8		H		

[a] Classes with the same letter grouping do not differ in MC increase value at = 0.05.

Table 6—Average equilibrium moisture content obtained at various relative humidities at 73°F (23°C)

	Equilibrium moisture content (%)												
	Adsorption				Desorption			Adsorption		Desorption			
Class	Des-sic.	33	58	79	58	33	Des-sic.	Des-sic.	97	79	58	33	Des-sic
1	1.5	4.9	7.0	9.3	7.8	5.4	1.5	1.3	18.3	13.3	9.7	6.1	1.9
2	1.5	4.8	7.0	9.8	8.2	5.6	1.7	1.1	19.6	14.1	10.0	6.2	1.7
3	1.3	4.4	6.5	9.4	7.9	5.4	1.6						
4	1.0	4.1	6.1	9.0	7.6	5.0	1.4						
5	1.4	4.5	6.5	9.5	7.9	5.4	1.5						
6	1.1	4.2	6.2	9.2	7.7	5.1	1.7	1.3	18.9	13.6	9.9	6.2	2.2
7	1.6	4.6	6.8	9.6	8.0	5.4	1.9	1.4	19.0	13.6	10.2	6.1	2.2
8	2.2	6.2	8.8	11.9	9.9	6.9	2.8						
9[a]	1.7	4.7	7.1	10.9	8.9	5.9	2.3	1.8	21.1	14.2	9.9	6.3	1.7
10	1.6	4.6	6.8	9.0	7.6	5.4	2.1						
11	1.7	4.8	6.7	8.7	7.2	5.2	2.1						
12	1.3	4.2	6.1	9.0	7.6	5.2	2.5						
13	1.6	4.1	5.7	8.1	7.0	4.4	1.5						
14	2.1	5.1	6.9	9.4	8.1	5.6	1.8						
Avg.[b]	1.5	4.7	6.7	9.5	8.0	5.4	1.9	1.4	19.4	13.7	9.9	6.2	1.9
Avg.[c]	1.5	4.7	6.7	9.4	7.9	5.4	1.9	1.4	19.4	13.7	9.9	6.2	1.9

[a]OSB siding.
[b]Average of all classes for which measurements are available.
[c]Average of all hardboard classes for which measurements are available (excluding OSB).

class 11 board.[3] The toluene-extracted material was solid at room temperature (after evaporation of the toluene solvent). Class 14 boards contained approximately 2.7% toluene-extractible material on an ovendry mass basis; for class 11 boards, the corresponding value was 2.6% extractible material.[4]

The chemistry lab also analyzed the extract by infrared (IR) spectroscopy. Absorbance spectra were similar for the extracts for the two board classes. In summary, board classes 11 and 14, which had very different water absorptivities, contained similar mass proportions of toluene-extractible material with similar IR absorbance spectra. These findings do not suggest an omission of wax sizing from class 14 boards.

Water Vapor Sorption

Sorption measurements progressed slowly, and even with the modified procedures described earlier, we encountered significant problems with mold growth at 97% RH exposure. The mold species on samples we submitted for mold identification were *Paecilomyces variotii*, *Penicillium* spp., *Taleromyces flavus*, *Penicillium corylophilum*, *Penicillium glabrum*, and *Aspergillus niger*. We observed no mold growth on specimens at equilibrium with 79% RH exposure. Because of mold growth, we were able to complete less than half the desorption measurements from 97% RH. The data in Table 6 are therefore incomplete. The table shows the results for adsorption measurements (samples are moved from dryer to wetter conditions) and desorption (samples are moved from wetter to dryer conditions).

Variation in equilibrium moisture content (EMC) between classes is relatively minor (Table 6). Class 8 has the highest EMC values, followed by class 9 (OSB). The EMC of all other classes is very similar. Figure 9 shows the average EMC for all hardboard siding classes (excluding OSB). Variation between samples within each class is also relatively small. The within-class standard deviation is 0.1% to 0.2% MC for most of the measurements but rises to around 1% MC for the EMC data at 97% RH.

Density

Average density for each class is presented in Table 7. Each density value shown is an average of 10 specimens from

[3]Class 11 and 14 boards were evidently made by the same manufacturing process.

[4]The mass percentages stated are based on a single extraction. A second extraction yielded approximately another 0.5% of toluene-extractible material.

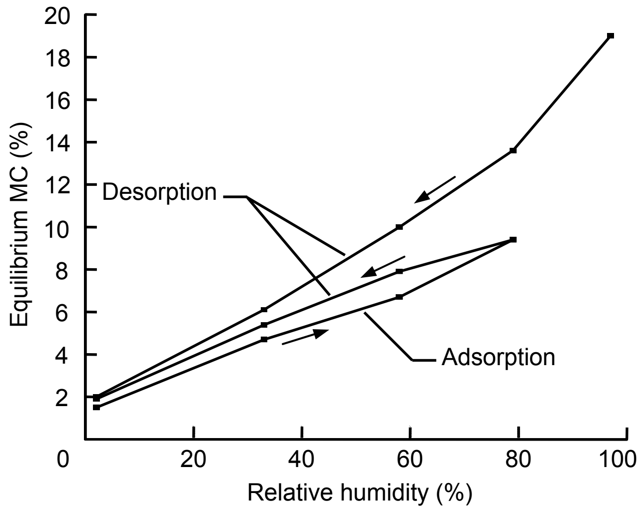

Figure 9—Sorption isotherms for hardboard, average of all classes (excludes OSB). The graph shows adsorption–desorption from desiccant to 79% RH and back, adsorption directly from desiccant to 97% RH, and desorption back down to desiccant on two separate sets of specimens. All data are for 73°F (23°C).

Table 7—Average density

Class	Average density (lb/ft^3 (kg/m^3))	Standard deviation (%)
1	46.8 (750)	3.2
2	47.0 (753)	3.2
3	44.9 (720)	2.3
4	45.6 (730)	4.1
5	47.8 (766)	2.9
6	47.4 (758)	2.7
7	48.4 (776)	1.8
8	52.8 (846)	2.9
9[a]	44.7 (717)	4.7
10	55.9 (896)	1.9
11	52.5 (841)	2.3
12	52.3 (838)	4.3
13	47.2 (756)	2.8
14	45.8 (733)	2.4

[a]OSB siding

each class. The non-commercial boards (classes 1 to 6) show no significant differences in density. The commercial hardboards fall into two categories: classes 7, 13, and 14 have similar densities, and the densities of classes 8, 10, 11, and 12 are somewhat higher.

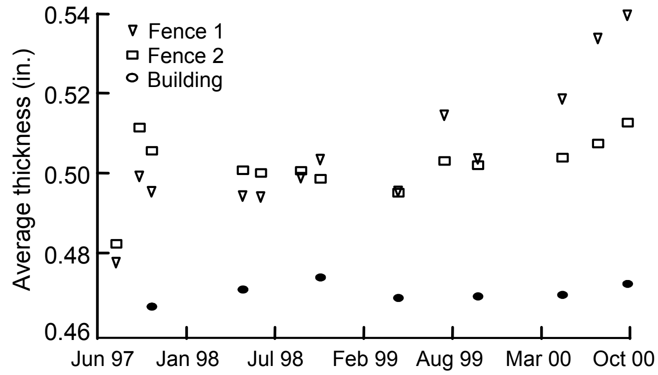

Figure 10—Average siding thickness as measured in place on the test fences and the building.

Outdoor Exposure Tests

Most of the results in this report are based on the last site inspections between September 26 and October 4, 2000. Class averages are reported, as are selected results of a board-by-board statistical analysis and statistical correlations between selected performance indicators as recorded on the test fences and laboratory test results.

Paint performance on all test specimens was generally good. No paint peeling, flaking, or erosion was observed. We observed only localized paint cracking near nail heads and on some drip edges, which was largely associated with in-service substrate swelling or installation damage. Our observation of good paint performance on hardboard siding agrees with previous research results (Feist 1982, 1990).

There was no visual evidence of decay in any of the boards on either fence, and we saw only minor amounts of mildew on some of the boards. Regarding mildew growth, it should be noted that the spray fence exposure employed in this study probably was not conducive to surface mildew growth. The fences were exposed to significant direct solar radiation, and the water spray was sufficient to flush the board surfaces. Surfaces exposed to extended periods of clinging moisture and little or no direct solar radiation are more prone to mildew growth (Forintek 2003).

Observed board warp ranged from wholly imperceptible to barely perceptible by visual estimate. However, in some cases it was enough to complicate in-place thickness measurements.

We observed no noticeable buckling during our inspections. The combination of relatively short test specimen length (0.57 m), industry-prescribed distance between nailing points (0.41 m), and wide gaps at each end of each specimen (6 mm) limited the likelihood of specimen buckling.

Thickness Measurements

Figure 10 shows the average thickness of all boards as measured in-place on the two test fences and the test

Table 8—Average thickness swell as measured on the fence during inspection between September 26 and October 4, 2000, and after reconditioning at 50% RH

	Thickness swell (%), fence 1				Thickness swell (%), fence 2			
	On fence		Reconditioned		On fence		Reconditioned	
Class	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
1	7.7	4.7	8.2	2.2	1.8	5.6	8.5	6.5
2	5.0	4.4	7.0	1.6	–0.9	5.2	4.1	2.2
3	12.5	5.1	10.4	2.3	4.4	6.9	9.4	3.5
4	14.5	4.5	12.3	2.5	5.5	6.1	10.0	4.6
5	23.0	7.1	18.0	4.5	21.7	8.1	23.5	6.1
6	28.0	6.6	22.0	4.0	18.5	7.7	22.5	6.3
7	10.4	4.7	9.3	1.6	2.9	4.3	7.9	4.9
8	15.3	7.1	21.2	3.0	9.2	4.5	17.4	7.9
9	13.0	6.6	13.5	3.9	5.7	6.1	12.4	3.4
10	13.0	6.7	12.8	3.4	0.4	6.2	8.5	4.2
11	3.7	6.1	5.6	3.0	–2.4	5.5	3.9	2.0
12	12.2	6.5	10.4	3.0	9.1	6.2	9.8	4.0
13	6.3	4.6	10.9	4.6	2.4	4.9	11.3	4.7
14	13.2	5.4	11.9	2.9	7.5	8.6	11.3	5.6

building. Although the average board thickness on fence 1 (cut drip edges) was less than that on test fence 2 during the early stage of the exposure, it continued to increase and surpassed the average thickness on fence 2 in 1998. In comparison, boards on fence 2 (drip edges intact) remained relatively stable. The siding on the building, which is not sprinkled daily, experienced no significant thickness swell over approximately 37 months of exposure.

Table 8 shows the class-average thickness swell, as measured on the fence during the final inspection (autumn 2000) and the thickness swell after reconditioning at 50% RH. The standard deviations within each class are also shown. It is difficult to draw conclusions from the measurements on the fence, given the large board-to-board variations. Apparent differences between classes are generally not statistically significant. The thickness swell values for classes 2 and 11 on fence 2, as measured on the fence, were negative. We believe these negative thickness swell values were due to large additive errors in measurement on the fence, both in initial and final on-fence thickness measurements. We feel that on-fence thickness measurements, despite the inherent individual measurement errors, when averaged over many specimens, are of some use for observing time trends in board thickness (as shown in Fig. 10). The magnitude and consistency of the differences in on-fence swelling between fences (which can be seen for individual board classes in Table 8) suggest a real between-fence difference (which can also be seen in Fig. 10). As discussed in following sections, edge welt data and data for paint cracks at nail heads further suggest that there was a real difference between fences. However, the errors in on-fence measurements were sufficiently large that we did not attempt to use these data for making comparisons between board classes.

Laboratory thickness measurements of the reconditioned specimens, after removal from the fence, and initial thickness measurements in the laboratory were far more accurate than the on-fence measurements. In contrast to on-fence swelling data, the reconditioned thickness swelling data show neither consistent nor substantial influence of painted drip edges. Board-to-board variation in the reconditioned thickness data, although less than in the on-fence thickness data, is still large enough that we did not attempt to use it to draw distinctions between board classes.

Edge Welt

Welt is a term sometimes used in the hardboard siding industry to describe localized swelling along panel edges (Baldwin 1988). The swollen area projects beyond the normal panel surface plane, and the surface within the swollen area is irregular (that is, not flat) (Fig. 11). Some degree of fiber raising can be expected in welted areas.

Some degree of edge welting at the horizontal drip edges developed in all classes of board, with the exception of class 9 (OSB siding). The textured surface of the OSB acted to obscure or hide localized edge swelling or roughening of the surface. We thus were unable to assess edge welt on the OSB siding.

We recorded the approximate area and severity of edge welt. Edge welt severity rating was a visual estimate, which was influenced by the degree to which the welt projected beyond the board plane, the abruptness with which it projected, and

Figure 11—Example of edge welt on fence 2 (drip edges intact). Specimen was rated on August 25, 1999, as having a welt severity of 9.0 and a welt area of 21 in^2 (EWI = 21).

surface roughness within the welt area. A rating of 10 indicates no perceptible welt; 9.5, welt could be perceived when the surface was viewed at an oblique angle; 9, welt was perceptible when the surface was viewed from a position normal to the board surface. Ratings lower than 9 indicate progressively more noticeable welt.

We combined area and severity into a single edge welt index that reflects both the extent and severity of edge welt, as follows:

$$I = \text{Area} \times (10 - \text{Severity}) \qquad (1)$$

The results in Table 9 show that all classes showed some welting but that some classes (11, 12, and 13) consistently had considerably less welting than other classes. Classes 2 and 10 experienced very little welting with the drip edge intact (fence 2) but fared less well on fence 1.

Drip edge welting always occurred earlier and to a more extensive degree than did welting along vertical edges, even on fence 2, where drip edges were painted and vertical cut edges were not. Welting along vertical cut edges did not become discernable in any of the specimens until May 2000. In contrast, most specimens that showed welting along their vertical edges in May 2000 had shown easily discernable drip edge welting by July 1998.[5] Where welting along vertical cut edges occurred, its presence was noted, but the degree of welting along vertical edges was not quantified. Values presented in Table 9 reflect welting along drip edges only. For board classes where welting along vertical edges occurred, the edge welt index values in Table 9 thus slightly understate the total extent of welting.

Visible fiber raising was common in welted areas, although in no cases did fiber raising result in rupture of the paint film. We could commonly observe fiber "telegraphing," in which fiber or fiber bundle outlines could be seen through intact paint surface films.

Light conditions influenced the degree to which a welt was perceivable. We therefore ensured that light conditions were similar at all welt inspections. Welt inspection was performed on sunny days, preferably when some degree of upper level cloudiness or haze was present. On days when sun exposure was judged to be too direct or intense, moveable translucent shading was used to limit light intensity; the west edge of the shading device was placed approximately even with the left (west) edge of the column of specimens being inspected. When moveable shading was used, the location of its edge varied with sun intensity and time of day. Welt inspections were always performed between 10:30 a.m. and 4:00 p.m.

Time trends in edge welt development are shown in Figure 12 for all classes combined. Edge welt generally became progressively worse over time, although at some intermediate inspection times welt was less perceivable than it was during the preceding inspection. These "reversals" in edge welt behavior coincide with in-place thickness measurement data, as shown in Figure 10. A decrease in thickness on both fences and an improvement in edge welt rating on fence 2 occurred over the winter of 1998–1999. This can be explained by the fact that the specimens were not sprayed over winter months, and thus were most likely drier in May 1999 than they were in November 1998. A decrease in thickness of specimens on the test building (Fig. 10) over the winter of 1998–1999 also suggests drying over that period. A decrease in thickness and an improvement in welt rating occurred on both fences between the mid-summer and autumn inspections in 1999. The likely explanation is that between August and October 1999, there was a 6-week period during which approximately 40% of daily spray events did not occur because of intermittent malfunction of the well pump.

From November 1998 through the final inspections in September–October 2000, the rate at which edge welting increased apparently accelerated. The greatest increase in welting occurred during the last year of exposure. By the end of the spray season in 1999, the specimens had experienced in excess of 400 spray events. Edge welting became noticeably more severe over the following year.

Also evident from Table 9 and Figure 12 is that a painted drip edge retarded development of edge welting.

Mildew

We saw only minor amounts of fungal discoloration of painted surfaces of some boards. The fungal species was identified as *Aureobasidium pullulans*. The paint and coatings industry generally refers to *A. pullulans* as a mildew fungus (Bussjaeger and others 1999, Zabel and Morrell

[5]This suggests that water retention in the laps played a role in welt development.

Table 9—Severity of drip edge welt and welt index, by class, as measured September 26 to October 4, 2000[a]

	Fence 1				Fence 2			
	Severity (10–0)[b]		Edge welt index		Severity (10–0)[b]		Edge welt index	
Class	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
1	8.3	0.5	48.2	17.1	9.5	0.7	4.6	8.4
2	7.9	0.6	30.4	14.8	9.8	0.3	0.5	1.1
3	7.9	0.4	64.8	17.2	8.8	0.6	13.3	11.6
4	7.7	0.3	66.6	14.5	8.8	0.8	12.2	14.2
5	7.8	0.2	71.1	12.8	7.6	0.4	51.0	13.5
6	7.6	0.5	72.6	21.6	8.0	0.6	32.9	12.6
7	7.6	0.5	51.3	17.0	9.4	0.6	3.3	7.2
8	8.0	0.4	50.8	13.1	8.5	0.5	23.6	12.8
9	NA	NA	NA	NA	NA	NA	NA	NA
10	7.8	0.5	23.1	10.7	9.7	0.5	0.2	0.4
11	8.2	0.4	9.8	4.0	9.6	0.6	0.3	0.8
12	8.6	0.5	13.9	7.1	9.0	0.3	5.9	4.1
13	8.8	0.4	4.7	3.8	9.4	0.5	2.1	3.3
14	8.7	0.6	44.9	54.2	9.1	0.6	24.9	40.6

[a]Does not include welting along vertical edges.
[b]Lower numbers mean greater severity.

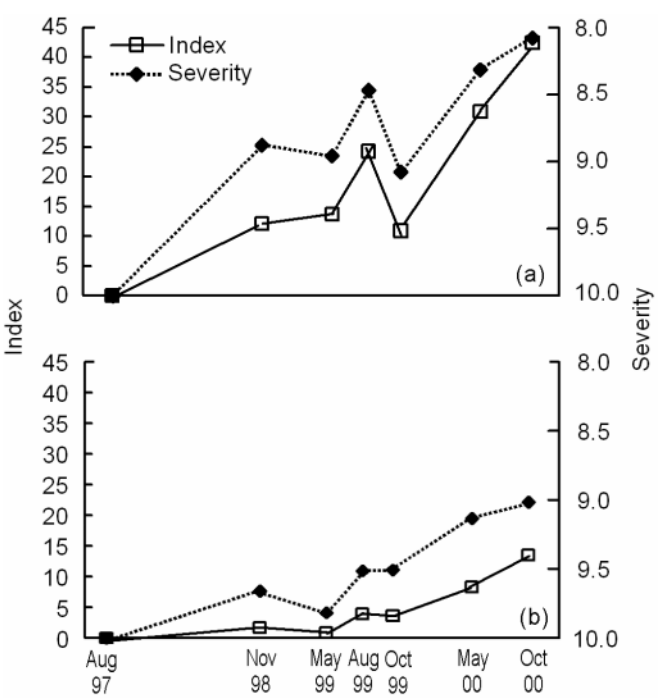

Figure 12—Edge welt behavior over time. (a) Fence 1 (drip edges cut); (b) fence 2 (drip edges intact).

1992).[6] We recorded mildew in a similar manner as edge welt (area and severity) and calculated a mildew index with Equation (1). The results for the last inspection during fall 2000 are reported in Table 10. Mildew was more common on the non-commercial boards, perhaps because they were hand-primed with an alkyd primer.[7] Class 5 boards had more mildew than any of the other classes. We attribute the lack of mildew on the OSB siding to its zinc borate treatment.

Mildew growth on specimen surfaces was concentrated in distinct areas. Even on specimens that had intense patches of mildew growth, there were appreciable areas that were devoid of mildew. We therefore characterized mildew growth by measuring the surface area within which mildew was observed and assigning an intensity rating within that area. We used an adaptation of ASTM Standard D 3274 "Standard Test Method for Evaluating Degree of Surface

[6]Also, see the sidebar entitled "What is mildew?" in Forintek (2003).

[7]The alkyd primer contained soya alkyd resin. Soya alkyd resins are significantly more resistant to mildew growth than are unmodified plant-derived oils such as linseed oil, but they are generally viewed as having lower resistance to mildew growth than acrylic resins. The commercial boards were factory-primed with thermosetting primer, in which the paint resins were likely acrylic. Field application of acrylic emulsion paints is sometimes accompanied by problems stemming from the surfactants contained in them, but such problems would not be anticipated in factory-applied thermosetting emulsion paints.

Table 10—Severity of mildew and mildew index, by class, as measured September 26 to October 4, 2000

	Fence 1				Fence 2			
	Severity (10–0)[a]		Mildew index		Severity (10–0)[a]		Mildew index	
Class	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
1	9.0	1.8	2.6	5.0	9.8	0.9	0.4	1.8
2	9.4	0.8	0.7	1.6	9.9	0.4	0.3	1.5
3	7.8	1.8	4.3	4.4	8.6	1.6	2.9	7.1
4	8.2	1.6	4.5	6.1	8.7	1.9	3.0	6.1
5	7.1	2.2	11.3	14.1	6.1	1.5	16.6	14.7
6	7.9	1.3	4.0	4.2	6.9	2.1	7.6	8.5
7	9.6	0.6	0.5	1.0	10.0	0	0	0
8	8.7	1.0	4.1	5.4	9.5	0.8	0.9	1.4
9[b]	10.0	0	0	0	10.0	0	0	0
10	9.0	0.7	1.5	1.7	10.0	0	0	0
11	9.8	0.5	0.1	0.3	10.0	0	0	0
12	10.0	0	0	0	10.0	0	0	0
13	10.0	0	0	0	10.0	0	0	0
14	10.0	0	0	0	10.0	0	0	0

[a]Lower numbers indicate greater severity.
[b]OSB siding.

Disfigurement of Paint by Microbial Growth or Soil and Dirt Accumulations" (ASTM 1995b) for judging intensity rating within face areas containing mildew. While D 3274 appears to have been developed for surfaces on which mildew distribution is more uniform than it was on our specimens, we used the same approach to judge severity where mildew was present.

Although mildew growth was more severe on drip edges than on board faces, we did not attempt to measure mildew growth on drip edges. Mildew growth on drip edges was in some cases difficult to distinguish with certainty from dirt accumulation. Mildew growth on drip edges was also sometimes accompanied by appreciable algal growth, which made assessment of the degree and severity of mildew growth difficult. On fence 1 the drip edges were unpainted and dark, which made it difficult to see the dark gray or black mildew growth. On fence 2, the drip edge surfaces of board in classes 1 to 6 and 9 were significantly rougher than the preformed drip edges of boards in classes 7, 8, and 10 to 14, which would have confounded any attempt to compare mildew growth between classes. On board surfaces, mildew growth was somewhat more common in the proximity of lap areas than elsewhere. A plausible explanation is water retention in lap areas.

Paint Cracks

We documented the occurrence of paint cracks at the nails on fences 1 and 2 and on the drip edge on fence 2. Ratings for paint cracks around the nail heads were either "no" (with an assigned value of 0) or "yes" (assigned value of 1). We determined an average for each board by dividing the sum of the ratings by two (two nail heads). Thus, average values range from 0 to 1. Cracks at the drip edge were assessed according to severity: 0 (no cracks), 0.5 (minor, visible with a 10× hand lens), 1 (significant, visible without magnification at about 15 in. from the drip edge), and 2 (severe, visible without magnification at about 3 ft from the drip edge). Table 11 summarizes the results from the final inspection (September–October 2000) by siding class.

Differences in degree of drip edge cracking between classes were substantial, with some classes showing very little cracking, and other classes, namely classes 5, 6, 8, and 12, showing drip edge cracking that was significant or severe. The nature of drip edge paint cracking that we observed in class 12 boards differed substantially from that in boards in classes 5, 6, and 8, but they received the same drip edge crack rating with our evaluation criteria. Drip edge paint cracks in class 12 boards were substantially fewer in number but generally extended for longer distances along the drip edge. Board classes 5, 6, and 8 showed significant edge welting, as well as drip edge paint cracking, whereas boards in class 12 showed modest levels of edge welting (Table 9). A close inspection of spare unexposed boards of class 12 revealed that these boards contained inconspicuous press blows as shipped from the manufacturer. The press blows evidently opened during board exposure on the fence and showed up as cracks in the drip edge paint film.

Drip edge paint cracking seems to correlate with on-fence swelling (Table 8) and with moisture content at time of removal (Table 12). As discussed in a later section of this report, performance in the substrate weatherability test

Table 11—Paint cracks at the nail heads and drip edge, averaged by class, as recorded September 26 to October 4, 2000

	Fence 1		Fence 2			
	Cracks at nail heads		Cracks at nail heads		Drip edge cracks	
Class	Average[a]	Standard deviation	Average[a]	Standard deviation	Average[b]	Standard deviation
1	0.70	0.22	0.44	0.24	0.33	0.44
2	0.55	0.34	0.19	0.20	0.08	0.18
3	0.73	0.33	0.44	0.24	0.88	0.28
4	0.66	0.32	0.50	0.29	0.60	0.45
5	0.73	0.31	0.39	0.29	1.60	0.50
6	0.83	0.20	0.31	0.27	1.56	0.51
7	0.46	0.37	0.20	0.24	0.03	0.11
8	0.09	0.25	0	0	1.15	0.49
9[c]	0.88	0.25	0.69	0.32	0.93	0.18
10	0.26	0.25	0.08	0.14	0.55	0.32
11	0.29	0.35	0.19	0.25	0.28	0.38
12	0.68	0.27	0.31	0.30	1.40	0.50
13	0.78	0.26	0.59	0.26	0.60	0.38
14	0.59	0.32	0.30	0.28	0.82	0.30

[a]Values range from 0 (no cracks) to 1.
[b]Values range from 0 (no cracks) to 2 (most severe).
[c]OSB siding.

Table 12—Moisture content at time of removal (October 12 and 13, 2000) and after reconditioning at 70ºF, 50%RH

	Moisture content (%), fence 1				Moisture content (%), fence 2			
	At time of removal		Reconditioned at 70ºF, 50%RH		At time of removal		Reconditioned at 70ºF, 50%RH	
Class	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
1	8.1	0.6	8.1	0.3	8.8	2.6	8.2	0.2
2	8.2	0.4	8.5	0.3	8.8	1.0	8.7	0.2
3	8.7	0.5	8.4	0.2	8.9	0.6	8.5	0.3
4	8.6	0.4	8.5	0.2	8.6	0.5	8.4	0.3
5	9.0	0.7	8.5	0.3	9.4	0.6	8.7	0.3
6	8.9	0.4	8.6	0.2	9.0	0.7	8.7	0.3
7	9.2	0.5	8.5	0.3	9.3	0.7	8.6	0.3
8	13.9	2.4	10.3	0.4	13.1	0.9	10.3	0.3
9[a]	9.7	0.3	8.3	0.3	10.1	0.6	8.7	0.3
10	8.0	0.5	7.8	0.2	8.2	0.5	7.9	0.2
11	7.8	1.0	7.6	1.0	8.0	0.7	7.7	0.3
12	9.8	0.6	8.7	0.4	10.1	0.9	8.9	0.3
13	7.0	0.7	7.0	0.3	7.4	0.6	7.2	0.3
14	18.7	6.5	9.5	0.5	16.4	6.0	9.6	0.4

[a]OSB siding.

procedure correlated reasonably well with drip edge paint cracking. In contrast, the data for paint cracking at nail heads show no clear relationship with performance in any laboratory test or with any other behavior observed on the test fences.

We observed cracking of the paint film at some nail heads on the test fences and the house during the fall of 1997. On the house, we concluded that installation had resulted in some paint cracks at nail heads because the cracks not only occurred early on specimens that were never sprayed but also occurred without perceptible specimen swelling. The nail head areas of specimens on the test house were therefore touched-up with paint in spring 1998 when the weather became suitable for painting with latex paint. Similar paint touch-up was not done on the test fences, because we were less certain that cracking had resulted from installation damage. Because of uncertainty regarding the origin of some paint film cracking around nail heads, these data should be treated with circumspection.[8]

Paint cracking at a nail head, regardless of how minor, was registered as a crack occurrence. Initially, we did not record the severity of cracking. By the autumn inspection in 1998, we also began to record whether the nail head was pulled through the surface paint film and the degree to which pull-through had occurred. If less than half the circumference of the nail head had pulled through the film, the observation was rated as a "borderline" case and assigned a rating of 0.5. If half or more of the circumference of the nail head was pulled through the paint film, the observation was rated as a "yes" and the observation assigned a rating of 1.0.

Figure 13 shows trends for presence of paint cracking at nail heads on fences 1 and 2 and the degree to which nail heads are pulled through the paint film (severity) over the period from the autumn inspection in 1998 through the final inspection in autumn 2000. Ratings, in general, became progressively worse over this period. In contrast to edge welt ratings, which began accelerating after November 1998, the paint crack ratings increased at an approximately constant rate. Figure 13 indicates that presence and severity values parallel each other over time.

Paint cracking at nail heads does not seem to correlate with thickness swelling, edge welting, or cracking of paint on drip edges. Specimens in classes 5 and 6 underwent appreciable in-service swelling (Table 8), showed the highest values of edge welt index (Table 9), and showed the highest incidence of drip edge paint cracking (Table 11), but cracking at the nail heads was no worse than for classes 1 to 4 or for two of

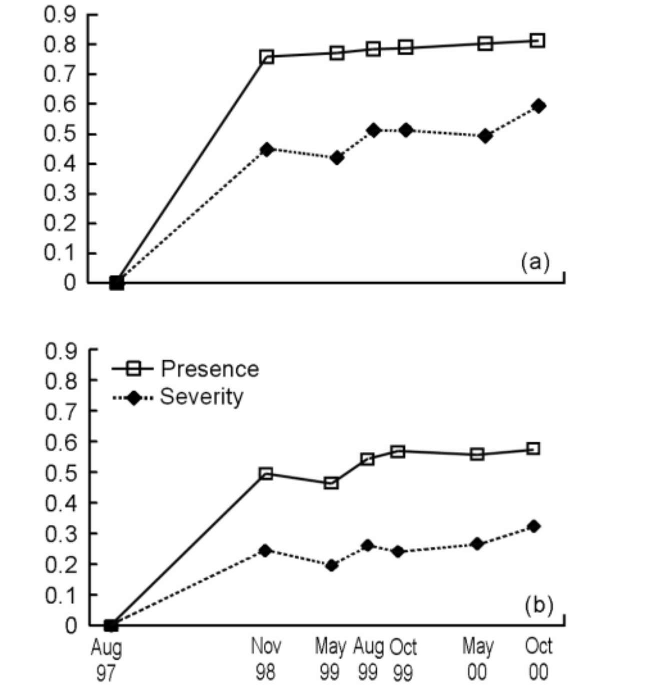

Figure 13—Paint cracks at nail heads. (a) Average of all boards on fence 1; (b) average of all boards on fence 2.

the seven classes of commercial hardboards. In addition, boards of class 8 performed poorly overall, and showed appreciable paint cracking on painted drip edges, but never developed paint cracks at nail heads on the same fence (fence 2). Boards in classes 5, 6, and 8 often showed distinct dimpling around the nail heads (that is, swelling around the nail head without cracking of the paint). Because the swelling in a dimple increased gradually with radial distance from the nail head, the strain on the paint film was moderate, which, in turn, kept it from failing. Consumers would probably object to dimpling of board surfaces around nail heads, even though dimpling does not result in paint film rupture.

Table 11 and Figure 13 indicate that a painted drip edge helped inhibit development of paint cracks at nail heads.

Moisture Content

Moisture contents at the time of removal (October 12 and 13, 2000) and after equilibrating the boards at 70ºF, 50% RH are shown in Table 12. Boards in classes 8 and 14 had appreciably higher final moisture contents than boards of the other classes. The higher final MC of class 8 correlates with higher MC values after reconditioning and with high equilibrium MCs in the vapor sorption tests (Table 6). Compared with other classes, class 14 displayed much higher water absorption in the 24-h edge water absorption tests (Tables 4 and 5), and class 8 also exhibited higher water absorption than most other classes. As discussed in the next section, boards in each of these classes showed more back-face water staining than did boards of the other classes. The back-

[8]It is also plausible that some paint cracking at nail heads was associated with nail head deflection caused by board linear expansion. We did not document nail head deflection out of the surface plane. This is a further reason to treat the data for paint film cracking at nail heads with circumspection.

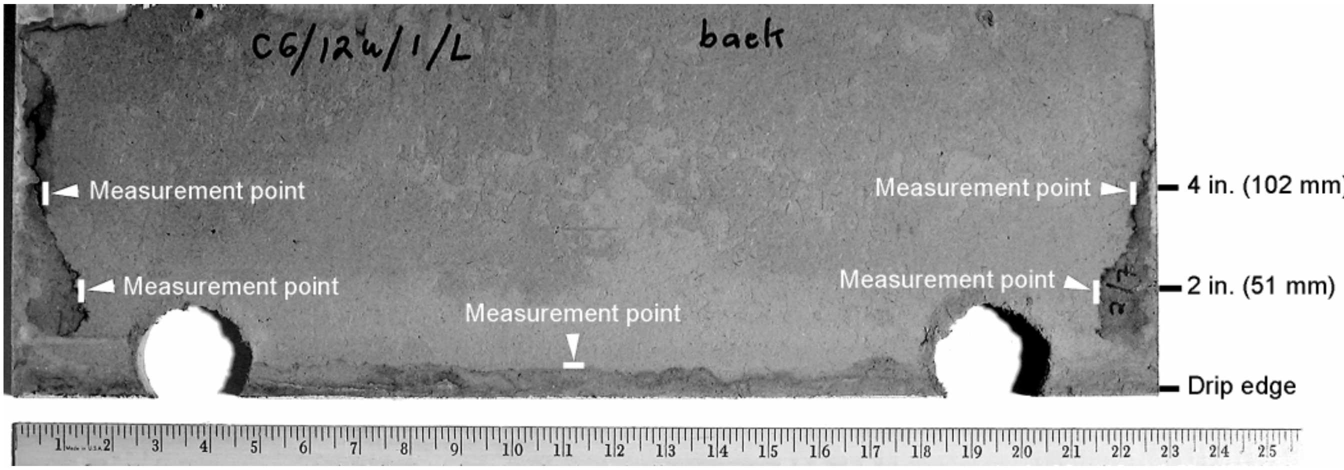

Figure 14—Locations of water stain measurements

face staining observations and the results of water absorption tests suggest that liquid water absorption played an important role in the high on-fence MCs of both of these board classes.

For all classes except 8 and 14, boards on fence 1 (which did not have painted drip edges) were slightly drier at time of removal than corresponding boards on fence 2. The water sprays had been shut off at the completion of the final inspection, roughly a week before specimen removal, and there had been virtually no rain during that week. If boards lacking a painted drip edge were wetter than corresponding boards with a painted drip edge at the time of our last on-fence thickness measurement and last inspection, the difference had vanished by the time boards were removed from the fence a week later. Only in the two classes of commercial board with the highest levels of liquid water absorptivity (classes 8 and 14) were boards on fence 1 wetter at time of removal than boards on fence 2.

Staining of Back Face

Specimens removed from the spray fences were evaluated for back face staining by measuring how far water stains extended in from the ends at four locations on each specimen and how far up from the drip edge at mid-length. Figure 14 shows the measurement locations.

It was generally possible to identify water stain marks that resulted from water coming from the back face of the specimen above, and these were ignored. Water staining at the top of a specimen appeared to be largely the result of water on the back face of the specimen immediately above it and was therefore not included.

Demarcation between stained and unstained areas was sometimes clear as an easily visible line that contrasted in shade with both the stained and unstained areas. In other cases, no clear demarcation line was visible. Stained areas were usually darker than unstained areas, but for some board classes with dark-colored back surfaces, the water-stained areas were of a lighter shade than the unstained areas. Where a measurement value for the border between stained and unstained areas could be discerned for only 5 or fewer of the 20 test specimens in a class–fence combination, measurement values are not reported. No attempt was made to measure stain intensity.

Stain extent measurements are shown in Table 13. The data indicate that stain extent in from the sides was similar on the two fences. Stain extent up from the drip edge generally appears to be greater on boards with painted drip edges (fence 2), but it is difficult to interpret the modest between-fence difference because of variability in the data and differences in the character of the laps.

For almost all board classes, the extent of stain up from the drip edge was significantly less than the lap dimension (1.25 in. (32 mm) on average for fence 2 and 1.125 in. (29 mm) inches on average for fence 1). For classes 8 and 14, the entire lap area was usually water-stained (Fig. 15), but we generally could not establish whether the water came inward from the sides or upward from the drip edge. Values for stain extent up from the drip edge for board classes 8 and 14 are therefore, for the most part, not reported in Table 13. The degree of back-face staining varied appreciably with board class, with board classes 8 and 14 showing significantly more extensive staining than any of the other board classes and the OSB siding consistently showing the least staining.

A cursory examination of relationships between MC at the time of removal and data on back stain suggested a stronger relation between the extent of staining inward from board ends and MC than between extent of staining upward from board drip edges and MC. This, along with the previously mentioned observation that water stains upward from drip edges usually remained well below the top of the lap area, suggests that no appreciable capillary rise of water in lap

Table 13—Average extent of water staining of the back of siding boards

Class	Extent of stain on fence 1 (in.)				Extent of stain on fence 2 (in.)			
	In from sides		Up from drip edge		In from sides		Up from drip edge	
	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
1	0.93	0.74	0.11	0.26	0.92	0.63	0.06	0.15
2	0.45	0.14	0	0.01	0.46	0.18	0.09	0.18
3	1.31	0.34	0.14	0.12	1.26	0.49	0.23	0.26
4	1.03	0.34	0.14	0.10	1.14	0.26	0.23	0.34
5	1.78	0.62	0.23	0.21	1.96	0.59	0.52	0.13
6	1.47	0.51	0.21	0.13	1.87	0.96	0.50	0.26
7	0.90	0.61	0.01	0.03	0.90	0.63	0.27	0.24
8	10.76	0.91	—	—	9.57	1.42	—	—
9	0.45	0.17	0.03	0.08	0.40	0.25	0.03	0.15
10	1.90	0.50	0.08	0.19	1.69	0.50	0.11	0.24
11	0.41	0.48	0	0.02	0.70	0.71	0.04	0.11
12	2.41	0.82	0.24	0.36	2.68	1.24	0.49	0.57
13	0.78	0.56	—	—	0.70	0.44	0.69	0.30
14	8.20	2.09	—	—	8.12	1.75	0.93	0.79

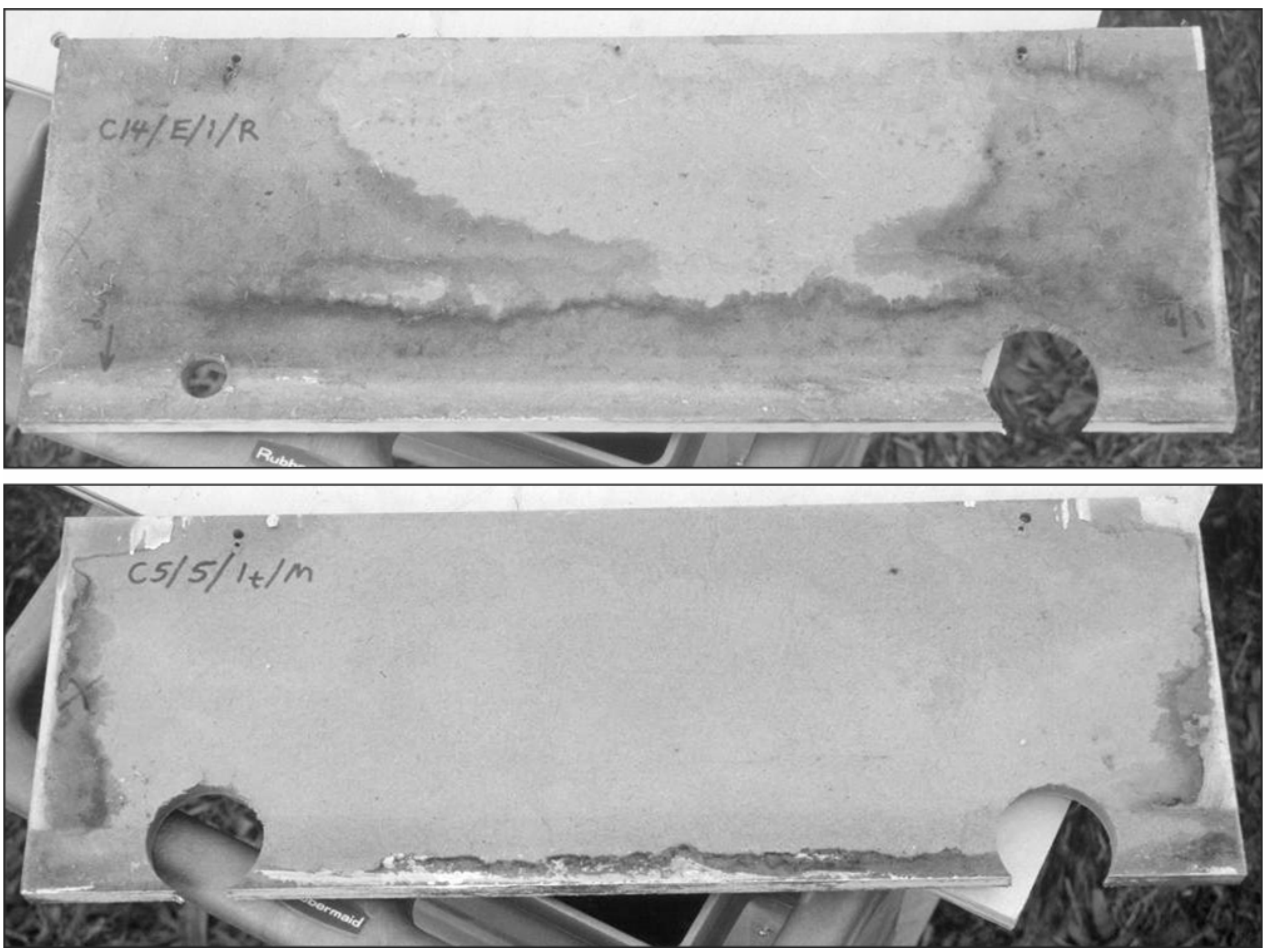

Figure 15—Back staining on class 14 and class 5 boards.

areas occurred. However, water tends to be retained longer in laps than on an open surface. The fact that we observed earlier and more extensive welting at drip edges than at vertical edges would be consistent with longer water retention times in laps. Our observations that mildew occurrence was (1) most extensive on drip edges and (2) somewhat more prevalent on board surfaces in the proximity of lap areas than at some distance from lap areas were also consistent with longer water retention times in laps.

Within specially made non-commercial boards (classes 1 to 6), stain extent tended to become greater with increasing (lab-measured) RTS value, although the relationship was far from monotonic. When all hardboards were considered, we detected no obvious correlation between (laboratory-measured) RTS value and the extent of back-face water staining. In contrast, both classes 8 and 14, which showed the most extensive staining, had shown significantly higher levels of edge water absorption in laboratory testing than did all other classes of commercial board and most classes of non-commercial board (Table 5).

Correlations With Residual Thickness Swell Test Results

We performed a board-by-board correlation between selected performance characteristics on the two fences and the results of the weatherability of substrate tests (that is, residual thickness swell). Each specimen on the fence was associated with two adjacent RTS specimens (see Fig. 3), and in our analyses we correlated performance values of individual test fence specimens with the average RTS value of those two RTS specimens.

Direct data plotting over the full data range usually showed only modest degrees of correlation and a great deal of scatter. This data scatter prevented us from establishing simple relationships that would allow us to quantify the potential effect of changes in the performance criteria in the ANSI/AHA standard. We therefore analyzed the data in terms of frequency (or probability) of occurrence of a failure or failure severity level within ranges of RTS values (RTS bins). This allowed us to determine the change in probability of occurrence of a certain value or value range for welt, mildew, or other failure, as a function of RTS. It also revealed in which RTS range the change in performance characteristics was the most rapid. To have a sufficient number of data points in each bin, we selected bins with an RTS range of 6%. For instance, the 15% RTS bin contains data for boards with an RTS between 12% and 18%. Table 14 shows the number of specimens in each RTS bin. The number of specimens per RTS bin reached a maximum at around 10% bin midpoint value and thereafter declined with increasing RTS. The number eventually became too small for meaningful data analysis.

Edge Welt as a Function of RTS

Figures 16 to 18 show the probability of occurrence of various levels of edge welt as a function of RTS on fence 1 at final inspection. Figure 16 depicts data for all hardboard classes on fence 1. The frequency of an edge welt index of over 50 (category D) increases steadily between the 5% and 11% RTS bins (2% to 14% RTS), and steeply increases in the 18% and 19% RTS bins (15% to 22% RTS). The frequency of category C index value ($30 < I < 50$) steadily increases from the 13% to 18% RTS bins, where category D begins to predominate. The 30% RTS bin and the bins beyond (RTS > 27%) contain only boards with a welt index over 50.

When consideration is confined to commercial board classes on fence 1 (Fig. 17), the data again show a steady increase in more severe welting (categories C and D) between the 8% and 18% RTS bins (5% to 21% RTS) and a steep increase in the most severe index level (category D) in the 19% and 20% RTS bins (16% to 23% RTS). Above 17% RTS (20% RTS bin) there are no boards with a welt index below 30.A strong relationship between RTS and edge welt also exists for the non-commercial board classes on fence 1 (Fig. 18). With these boards, severe welting ($I > 50$, category D) steeply increases at much lower RTS ratings, specifically between the 5% and 13% RTS bins (2% to 16% RTS). With a few exceptions, non-commercial boards on fence 1 with RTS ratings over 11% (14% RTS bin and higher) had severe welting.

Severe welting (category D) was less common on fence 2 than on fence 1 (Figs. 19 to 21 compared with Figs. 16 to 18); the painted drip edges on fence 2 evidently retarded the development of severe welts. Figures 19 to 21 more clearly show a decreasing frequency of boards with low welt index values as RTS increases. Figure 19 (all boards on fence 2) shows that the frequency of boards with the lowest edge welt index (category A, $I = 0$ to 10) steadily drops with RTS between the 5% and 14% RTS bins and then drops more rapidly in the 15% and 16% RTS bins. Higher edge welt index categories (C and D) begin to increase markedly at the 16% RTS bin. No strong correlation seems to exist at RTS levels beyond 25% except that the number of boards with an edge welt index between 30 and 50 (category C) gradually increases with RTS. When non-commercial boards are excluded from the analysis (Fig. 20), the same gradual drop in number of boards with the lowest index (A) occurs at lower RTS ratings, with a sharp drop at the 15% and 16% RTS bins. More severe edge welt categories (C and D) begin to increase at RTS over 17% (14% RTS bin).

As on fence 1, the non-commercial boards on fence 2 show greater susceptibility to edge welt than do commercial boards at a given RTS level, even in the lower RTS bins (compare Figs. 20 and 21). The frequency of boards with little or no edge welt (category A) declines rapidly between the 14% and 18% RTS bins (11% to 21% RTS).

Table 14—Number of specimens in each RTS bin

RTS bin		Number of specimens per bin					
		All boards[a]		Non-commercial		Commercial[a]	
Center (%)	Range (%)	Fence 1	Fence 2	Fence 1	Fence 2	Fence 1	Fence 2
5	2–8	88	81	43	37	45	44
6	3–9	103	102	52	49	51	53
7	4–10	111	119	58	60	53	59
8	5–11	114	119	54	55	60	64
9	6–12	118	116	50	50	68	66
10	7–13	118	120	47	43	71	77
11	8–14	111	115	35	39	76	76
12	9–15	103	102	26	31	77	71
13	10–16	98	88	22	19	76	69
14	11–17	76	69	15	15	61	54
15	12–18	51	49	10	9	41	40
16	13–19	34	32	5	7	29	25
17	14–20	22	26	5	8	17	18
18	15–21	21	19	11	4	10	15
19	16–22	19	14	12	7	7	7
20	17–23	21	18	16	12	5	6
21	18–24	21	22	18	18	3	4
22	19–25	22	20	20	18	2	2
23	20–26	23	18	21	16	2	2
24	21–27	21	22	19	21	2	1
25	22–28	17	22	16	21	1	1
26	23–29	13	19	13	18	—	1
27	24–30	12	14	12	14	—	—
28	25–31	11	15	11	15	—	—
29	26–32	9	16	9	16	—	—
30	27–33	6	11	6	11	—	—
31	28–34	7	8	7	8	—	—
32	29–35	8	7	8	7	—	—
33	30–36	7	6	7	6	—	—
34	31–37	5	3	5	3	—	—
35	32–38	5	3	5	3	—	—
36	33–39	5	4	5	4	—	—
37	34–40	4	4	4	4	—	—
38	35–41	3	3	3	3	—	—
39	36–42	2	2	2	2	—	—
40	37–43	2	2	2	2	—	—
41	38–44	2	1	2	1	—	—
42	39–45	1	—	1	—	—	—
43	40–46	1	—	1	—	—	—

[a]Does not include OSB boards.

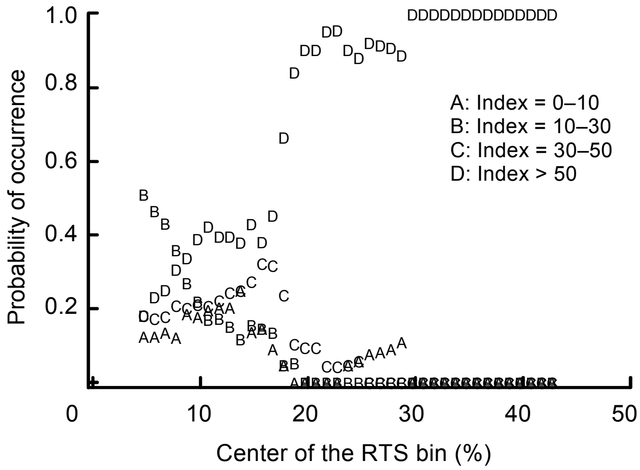

Figure 16—Edge welt index as a function of residual thickness swell (RTS), fence 1, all classes except OSB (class 9). Lower index means less welt.

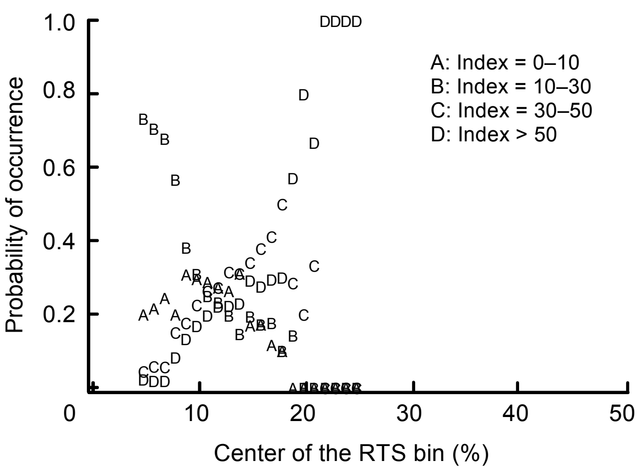

Figure 17—Edge welt index as a function of residual thickness swell (RTS), fence 1, commercial classes only (except OSB). Lower index means less welt.

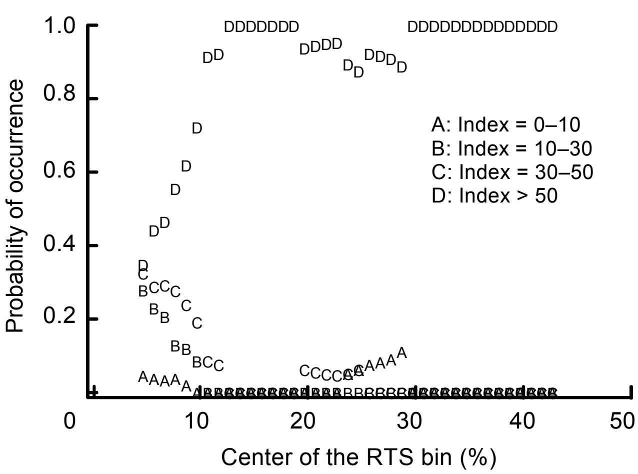

Figure 18—Edge welt index as a function of residual thickness swell (RTS), fence 1, non-commercial classes.

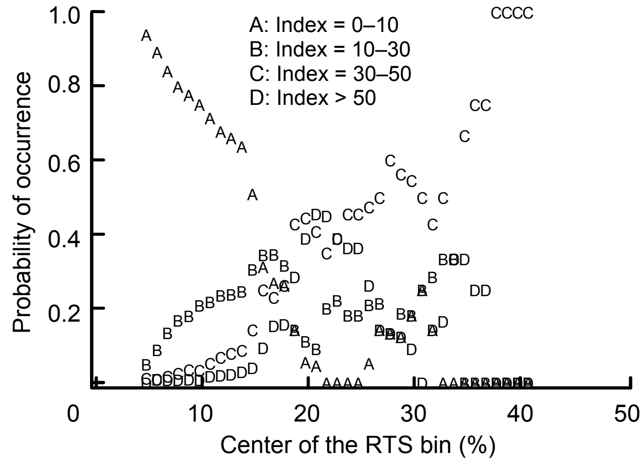

Figure 19—Edge welt index as a function of residual thickness swell (RTS), fence 2, all classes except OSB (class 9).

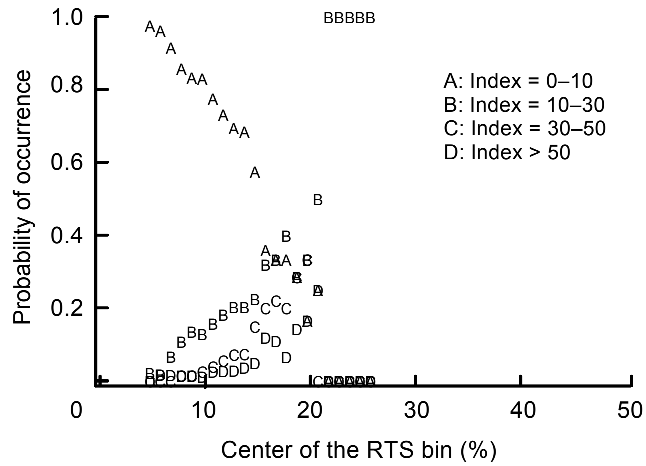

Figure 20. Edge welt index as a function of residual thickness swell (RTS), fence 2, commercial classes only, except OSB (class 9).

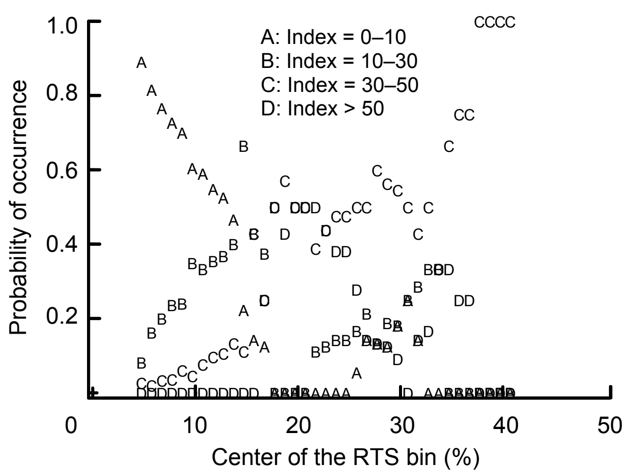

Figure 21—Edge welt index as a function of residual thickness swell (RTS), fence 2, non-commercial classes.

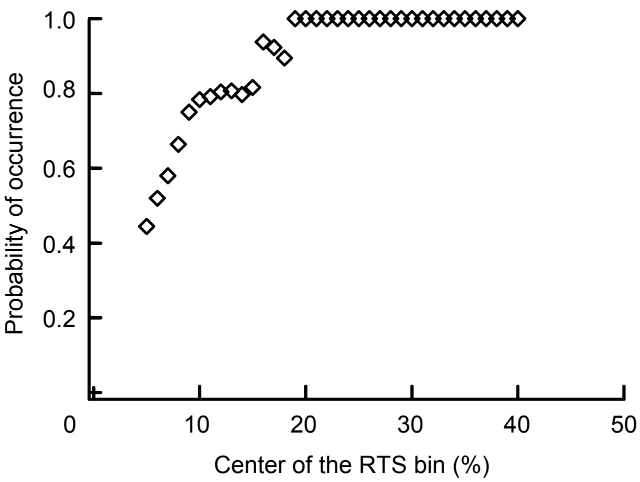

Figure 22—Probability of boards developing edge welt as a function of RTS, fence 2, all classes except OSB (class 9).

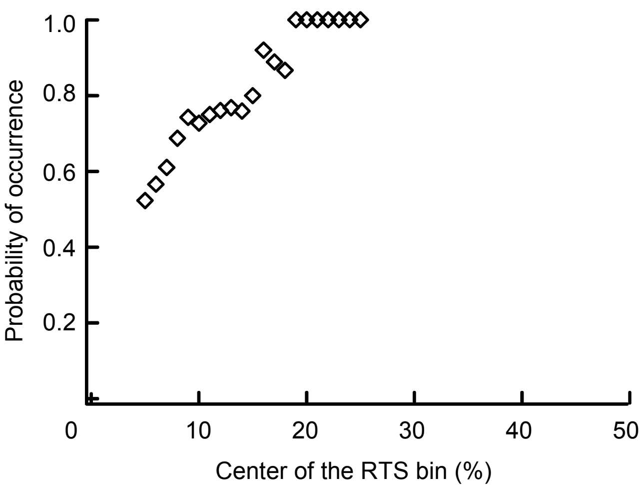

Figure 23—Probability of boards developing edge welt as a function of RTS, fence 2, commercial classes only, except OSB (class 9).

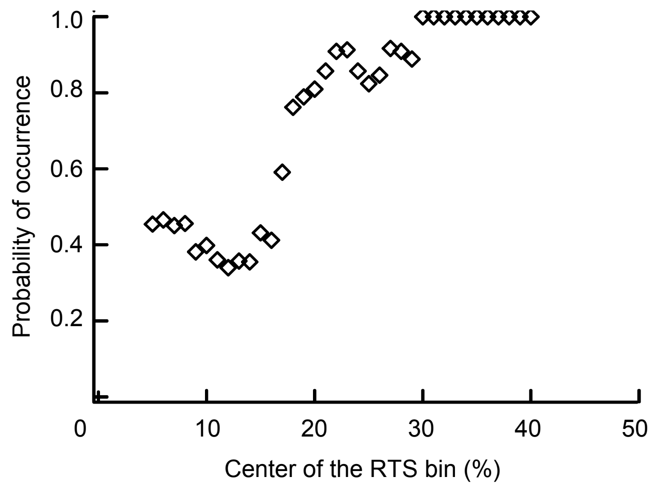

Figure 24—Probability of boards developing mildew as a function of RTS, fence 1, all classes except OSB (class 9).

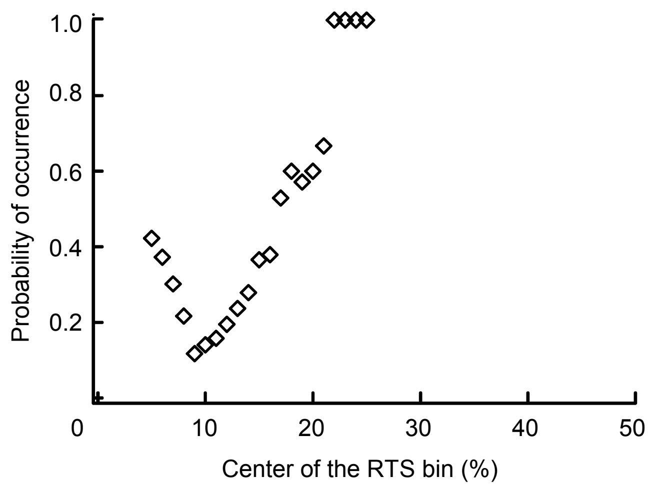

Figure 25—Probability of boards developing mildew as a function of RTS, fence 1, commercial classes only, except OSB (class 9).

Another way of viewing the results is to graph the probability of a board showing any edge welt as a function of its RTS rating. Figures 22 and 23 show the results of this analysis for fence 2, with and without non-commercial classes, respectively. Figure 22 shows an increase with RTS in the occurrence of welted boards in RTS bins below 19%, with the steepest increase between the 5% and 9% RTS bins and a more gradual increase between the 10% to 18% bins. Above RTS = 16% (19% RTS bin) all boards have edge welts. The data for commercial boards (Fig. 23) show similar trends.

In summary, the data indicate that the current 20% RTS criterion in the ANSI/AHA standard does exclude boards that are prone to serious edge welting but that the incidence and severity of edge welting may be further reduced, and to a significant degree, if the RTS criterion were lowered from 20% to 16% or 17%. Even further reduction in the probability of welt incidence and severity would be expected if the level were to be reduced still more.

Mildew as a Function of RTS

The mildew index does not correlate as well with RTS as does the edge welt index. Figures 24 to 29 show the occurrence of mildew as a function of RTS ratings. When all classes on fence 1 are included (Fig. 24), the data show a sharp increase in the occurrence of mildew after the 16% RTS bin (13% to 19% RTS) and mildew on all boards with an RTS rating of 27% or greater (30% RTS bin). Without the non-commercial classes (Fig. 25), the data show similar trends but not as clearly. Mildew occurrence increases

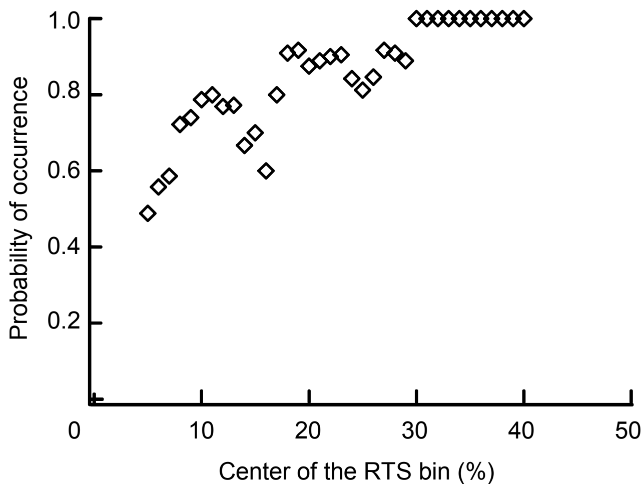

Figure 26—Probability of boards developing mildew as a function of RTS, fence 1, non-commercial classes only.

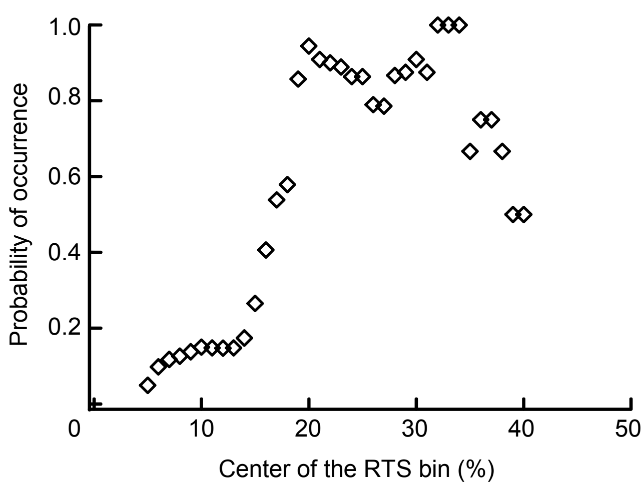

Figure 27—Probability of boards developing mildew as a function of RTS, fence 2, all classes except OSB (class 9)

rapidly at the RTS = 17% bin, but the correlation at lower RTS values is not clear. Commercial boards on fence 1 with an RTS rating of 19% (22% RTS bin) or higher all had mildew. Mildew occurrence on the non-commercial classes on fence 1 increases more gradually and consistently with RTS (Fig. 26) between 2% RTS and 27% RTS. All non-commercial boards with an RTS rating over 27% (30% RTS bin and higher) had mildew.

The data for fence 2 (drip edges intact, Fig. 27) give somewhat different results. The likelihood that boards had mildew rapidly increases after the 13% RTS bin (10% to 16% RTS), but after the 20 RTS bin (17% to 23% RTS) there appears to be no clear correlation. When non-commercial classes are excluded from the data (Fig. 28), a somewhat clearer picture emerges. Occurrence of mildew increases sharply after the

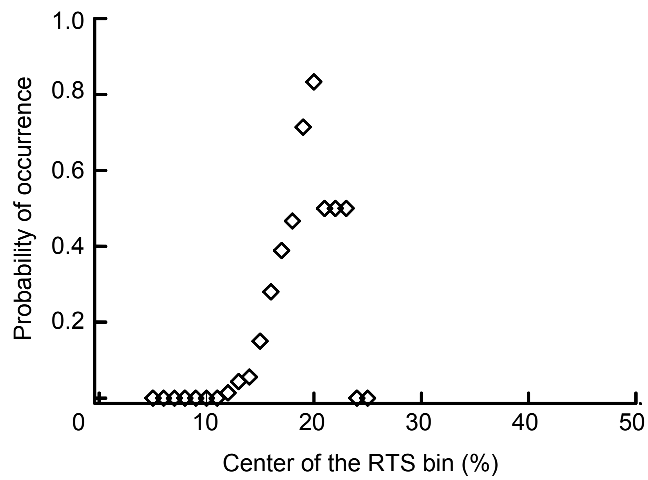

Figure 28—Probability of boards developing mildew as a function of RTS, fence 2, commercial classes only, except OSB (class 9).

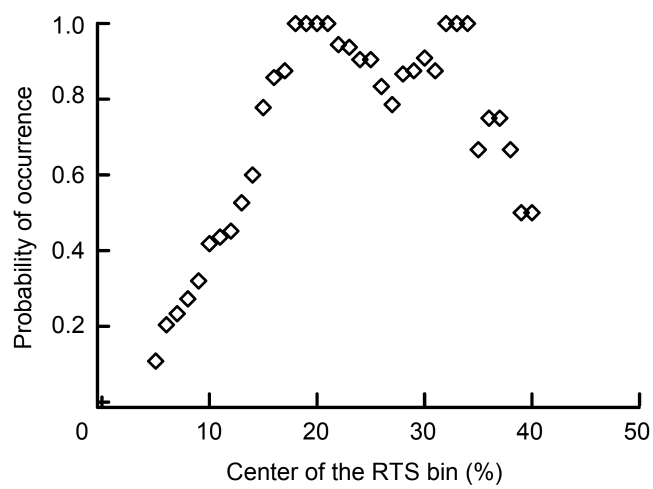

Figure 29—Probability of boards developing mold or mildew as a function of RTS, fence 2, non-commercial classes only.

14% RTS bin (11% to 17% RTS). However, the correlation fails at RTS values of 24% and higher (21% RTS and higher bins) because the sample size is reduced to four specimens or fewer, and the specimen with the highest RTS value had no mildew. Mildew on the non-commercial boards on fence 2 increases rapidly with RTS between 2% RTS and 21% RTS (5% RTS and 18% RTS bins). Mildew occurrence remains high at RTS values over 21% until it seems to drop off after the 34% RTS bin. However, only four or fewer specimens are in these higher bins, and the results are skewed by one specimen without mildew having an extremely high RTS rating.

In summary, although occurrence of mildew is obviously related to multiple factors, mildew correlates reasonably well with RTS, and the data suggest that the incidence of mildew

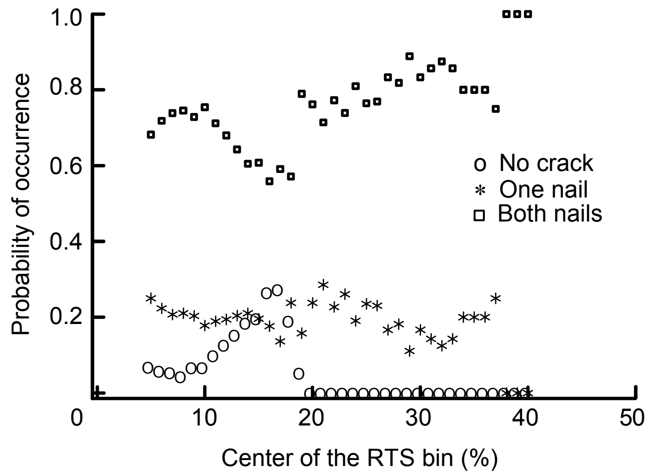

Figure 30—Occurrence of cracks at nail heads as a function of residual thickness swell, fence 1, all classes except OSB (class 9).

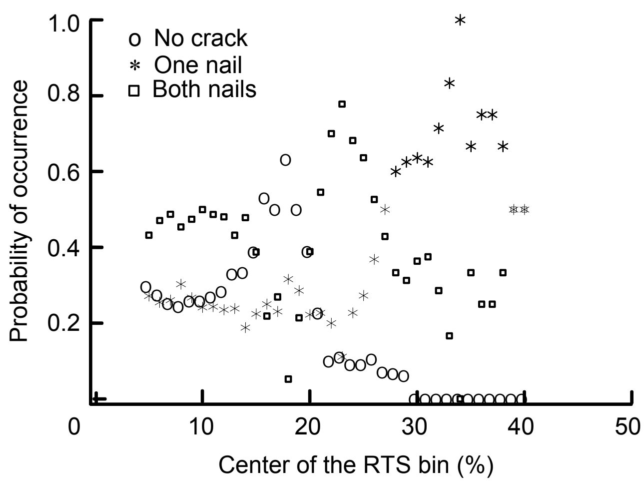

Figure 31—Occurrence of cracks at nail heads as a function of residual thickness swell, fence 2, all classes except OSB (class 9).

may be reduced by lowering the RTS requirement in the ANSI/AHA standard from 20% to 16% or 17%. However, the data do not show that further significant improvement can be expected by dropping the criterion below 16% RTS.

Paint Cracks at Nail Heads as a Function of RTS

Figure 30 shows the occurrence of paint cracks around the two nail heads of boards on fence 1 as a function of RTS. All board classes are included. The results show no clear correlation, except that there are no boards without cracks if the RTS is 17% or higher (20% RTS bin).

Figure 31, which depicts corresponding data for fence 2, also shows little correlation between the occurrence of cracks around nail heads and RTS. On fence 2, the frequency of boards without cracks declines for RTS bins beyond 21% (RTS > 18%). Above RTS of 27% (30% RTS bin and higher), all boards from fence 2 showed paint cracks.

In summary, paint cracks around nail heads did not correlate well with RTS, although boards with RTS over 20% tended to have more cracks. We thus have no evidence that lowering the current RTS requirement of 20% would decrease the incidence of paint cracking around nail heads. This conclusion may be limited to prefinished siding, where paint cracking due to installation may obscure any effect of thickness stability (RTS rating). With site-finished hardboard siding, RTS level might have a greater influence on occurrence of paint film cracking at nail heads than we observed in this study.

Nail Heads Through the Surface as a Function of RTS

Figure 32 shows the correlation of occurrence of nail heads penetrating the paint surface with RTS for all classes on fence 1. This was also referred to previously in this report as “severity” of paint cracks around the nail head. “Borderline” indicates that one nail head was rated borderline (0.5). “Moderate” penetration means that one nail had fully pulled through (rated at 1) or that two nail heads were rated borderline. “Significant” indicates one complete pull through and one borderline, and “severe” means that both nail heads had completely pulled through the surface. No clear correlation appears to exist below 20% RTS, but above that level the number of boards without penetration begins to drop off. The RTS bins of 26% and higher contain no boards without penetration, which means that all boards with a RTS of over 23% showed nail head surface penetration.

There was no apparent correlation between nail head penetration through the paint surface and RTS on fence 2 (Fig. 33), even at high RTS ratings. Some boards with very high RTS ratings did not have any nail heads penetrating the surface. As discussed previously in this report, these boards often had considerable thickness swelling around the nail heads, but the swelling was gradual and the paint film was evidently capable of accommodating the dispersed strain.

In summary, as with paint cracks around nail heads, nail head penetration of the paint surface did not correlate well with RTS. The same limitation that applies to our findings concerning paint cracks at nail heads also applies to our findings concerning nail head penetration.

Drip Edge Paint Cracks as a Function of RTS

Figure 34 shows the correlation of probability of occurrence of various drip edge crack ratings with RTS. The data show a strong inverse correlation between frequency of boards without drip edge cracks and RTS. The frequency of such

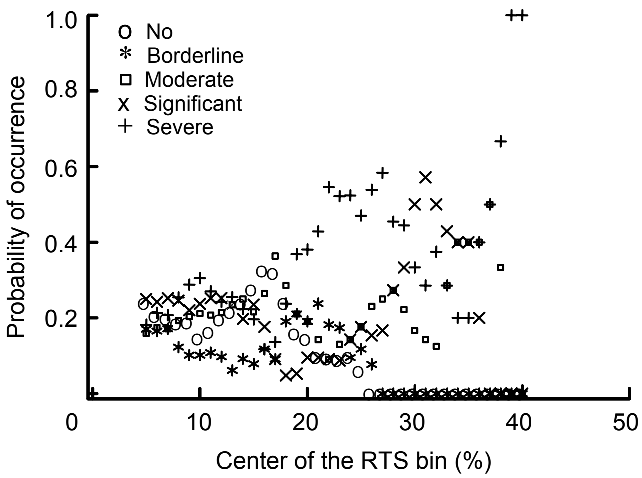

Figure 32—Occurrence of nail heads penetrating the paint surface as a function of residual thickness swell, fence 1, all classes except OSB (class 9).

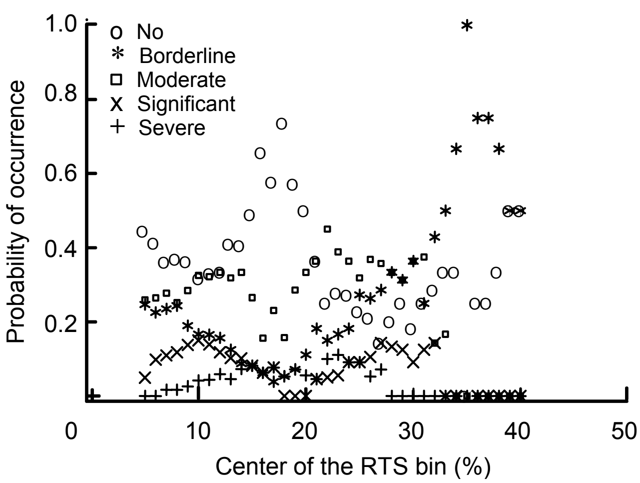

Figure 33—Occurrence of nail heads penetrating the paint surface as a function of residual thickness swell, fence 2, all classes except OSB (class 9).

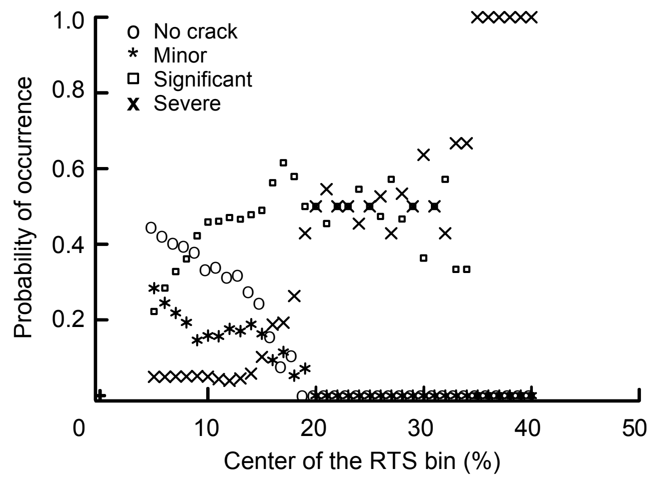

Figure 34—Occurrence of cracks on the drip edge as a function of residual thickness swell, fence 2, all classes except OSB (class 9).

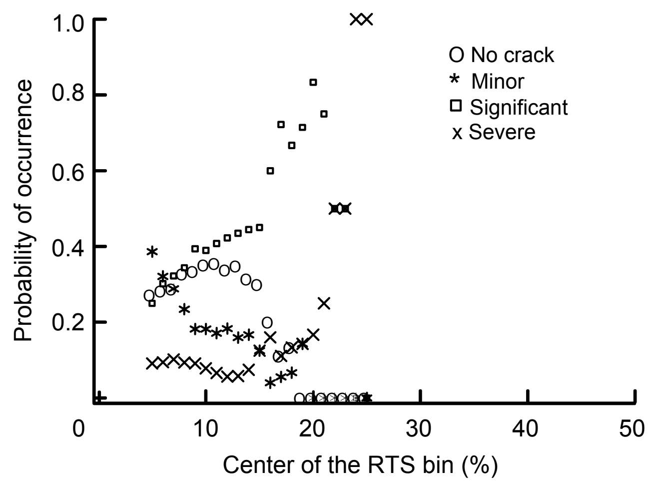

Figure 35—Occurrence of cracks on the drip edge as a function of residual thickness swell, fence 2, commercial classes only, except OSB (class 9).

boards steadily declines with increasing RTS until, at 16% RTS and above (19% RTS bin and higher), no board specimens are without drip edge cracks. At 32% RTS and above (35% RTS bin and higher), all cracking is severe, but the number of specimens in those bins is very small (four or fewer).

When only commercial boards are considered (Fig. 35), the correlation between the number of boards without cracks and RTS is not as clear for RTS values below 15%, but a rapid decline is apparent when RTS increases from the 15% RTS bin to the 19% RTS bin. However, the occurrence of significant drip edge cracking increases steadily from extremely low RTS values up to the 20% RTS bin, with an especially rapid increase after the 15% RTS bin (RTS > 18%). Boards with RTS ratings of over 16 % (19% RTS bin) all had drip edge cracks, and the occurrence of severe cracking begins to increase significantly beyond the 19% RTS bin.

In summary, paint cracking on the drip edge correlated well with RTS, showing a marked increase for boards with RTS ratings over 18%. The data also suggest that lowering the RTS requirement beyond 18% is likely to yield additional improvement in drip edge performance.

Summary of Correlations

Correlations of test fence performance with residual thickness swell (RTS) test results can be summarized as follows:

- Edge welt correlated well with RTS. The data suggest that lowering the RTS test criterion to 16% or 17% would be beneficial and that lowering it still further would have additional benefits.

- Mildew growth correlated reasonably well with RTS. Lowering the RTS criterion to 16% or 17% would likely reduce mildew growth on boards, but further reductions are unlikely to be beneficial.
- Paint cracking of the drip edge correlated well with RTS. The data suggest that lowering the RTS criterion to 18% would have a beneficial effect and that further reductions would yield additional benefits.

Issues Related to Standard ANSI/AHA 135.6

Besides pass–fail criteria, other issues related to the weatherability of substrate test procedures in the ANSI/AHA A135.6-1998 standard are worth noting. The standard does not specify any statistically based procedures that would ensure, at a specific level of confidence, that a product meets the standard's performance requirements. Instead, it implies that all specimens (in a sample selected for purposes of certification testing) must meet the test criteria, without specifying sample size, frequency of sampling, or how specimens should be selected. It appears that in practice, sample size for certification testing is sometimes very small (Carll and others 2000).[9]

In this study, we found that a significant minority of specimens of one class of commercial board failed to meet ANSI/AHA requirements, even though the board was grade-stamped as conforming to the standard. Biblis (1989) apparently had a similar experience. The 100% passage rate requirement for specimens in the certification sample, implied in the ANSI/AHA standard, does not guarantee that all boards in the population associated with that sample also meet test criteria requirements.

We believe that the standard would be more meaningful if it specified a statistical confidence level with which the product can be expected to meet the standard's RTS requirement. If the sample size were 10 randomly selected specimens and we assumed a normal distribution, a 95% confidence level for the board population that the sample is assumed to represent would translate to the following pass–fail criterion:

Average + (1.8 × standard deviation) < maximum RTS requirement

where standard deviation is the standard deviation of the individual measurements. If the required number of samples were lowered, the multiplier value for the standard deviation value would need to be raised in order to maintain the same confidence level. A similar approach could be followed for all other test requirements (such as linear expansion, water absorption) in the standard.

The measures above, by themselves, address only the variability in the sample population, not variations in the product over time. Variability over time can be addressed only by an effective in-plant quality control program, frequent random sampling and testing, or both.

Conclusions

We observed the following in laboratory testing:

- RTS and 24-h edge water absorption test results varied considerably between commercial hardboards.
- Most of the commercial hardboard siding tested met the industry criterion of 20% maximum RTS. However, 14% of tested specimens from one of the classes of commercial hardboard exceeded 20% RTS.

We observed the following on the water-sprayed test fences:

- The most noticeable failure mode was surface welting, which occurred earlier and to a greater extent near drip edges (in lap areas) than it did on board end cuts. The next most noticeable failure modes were paint film breakage on drip edges and board swelling that resulted either in cracks in the paint film at the nail heads or in "dimpling" around nail heads.
- There was no noticeable buckling, but test specimen size and attachment to the fences was such that noticeable buckling would have been unlikely.
- We found no visible evidence of decay in any of the siding. Open end joints at board ends evidently permitted water entry but also afforded drainage and drying.
- We only found minor amounts of mildew on the painted surfaces of some boards. However, the exposure regimen (appreciable sun exposure and daily spraying with quantities of water sufficient to flush the board surfaces) may not have been conducive to mildew growth.
- Paint performance was generally good, even on the test fence where drip edges had been removed.
- There were substantial differences in performance of commercial boards, especially with regard to edge welting.
- A painted drip edge substantially retarded development of surface welting at the drip edge, reduced the magnitude of measured in-service swelling, and reduced development of paint cracks at nail heads.

Correlations between laboratory RTS data and performance on the fences showed the following:

- Direct correlations of RTS and any given measurement of field performance were rarely strong. There was usually

[9] See table 1 of Carll and others (2000).

substantial scatter in the data, but RTS nevertheless often was a useful indicator of field performance.

- RTS proved to be a good indicator of the likelihood of edge welting. The data suggest that lowering the test criterion in AHA/ANSI Standard A135.6 to 16% or 17% would noticeably reduce the incidence of edge welting in service and that lowering it still further would have additional benefits.
- RTS proved to be a reasonably good indicator of likelihood of mildew growth on painted surfaces. The data suggest that lowering the RTS criterion in the standard to 16% or 17% would likely reduce the incidence of mildew growth in service but do not suggest that further reductions would be beneficial.
- RTS proved to be a good indicator of the likelihood of paint cracking on drip edges. The data suggest that lowering the RTS criterion in the standard to 18% would noticeably lower the incidence of drip edge paint cracking and that further reductions would yield additional benefits.

Our review of the current version of ANSI/AHA Standard A135.6 for hardboard siding led us to the following conclusions:

- The standard lacks an appropriate statistical basis for sample selection.
- The standard does not account for the effects of variability in the test results.

Other conclusions and observations:

- The degree of back-surface water staining varied appreciably between commercial hardboards. Despite significant water staining on the back surface of some boards, there is no convincing evidence that vertical capillary suction in the laps between boards played a significant role in back-surface wetting. With the short specimen length and open end joints, migration of water from board ends appeared to play a substantial role in back-surface wetting. However, retention of water in lap areas may be an important factor in board degradation.
- We saw considerable mold growth on specimens exposed to 97% relative humidity (RH) during the sorption tests but no visible mold on any of the specimens maintained at 79% RH.

Recommendations

Based on our conclusions and observations, we make the following recommendations

- ANSI/AHA Standard A135.6 should be revised to include statistically based criteria for sample selection.
- Statistically based pass–fail criteria should be added to the standard that account for the variability in the individual measurements and the number of samples measured.
- The RTS pass–fail criterion in the standard should be lowered to 17% or lower. Although there likely would be additional performance benefits from lowering the criterion further, we believe that such a decision should also be based on factors such as the effect on mill operation and economics, which are outside the scope of this report.

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