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Performance of Back-Primed and Factory-Finished Hardboard Lap Siding in Southern Florida

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Abstract

Because of performance problems with hardboard siding in southern Florida, the U.S. Department of Housing and Urban Development (HUD) proposed a local standard requiring prefinishing of siding and priming of all siding surfaces, including the back. However, the effectiveness of these practices was questioned. To determine if back-priming or factory finishing improves durability and performance of hardboard siding, we installed factory-finished and factory-primed siding on two buildings in southern Florida. The buildings were identical except that one had gutters and no overhangs and the other had overhangs and no gutters. Half the siding was back-primed and half was not. Moisture content, temperature, and air pressure difference across the siding were continuously monitored for 2 years. Condition and thickness of siding boards were recorded every 3 months. After removal from the buildings, siding was inspected and final moisture contents were determined. The siding was in excellent condition after about 2½ years of outside exposure. There was no evidence that back-priming the siding reduced its in-service moisture content. Whether the siding was from the overhang building or the guttered building did not seem to make a difference, but inspection of the windows and final moisture contents of the trim strongly suggested that overhangs provided additional protection on the gable ends (gutters were only present on the sidewalls).

Keywords: hardboard, siding, moisture, moisture content, air pressures

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Research Summary

The goal of this project was to determine if back-priming or factory-finishing improves the durability and performance of hardboard siding when installed according to recommended practice. The total project length was 34 months with a planned data collection period of 24 months. The work was performed under a Sponsored Research and Development Agreement between the USDA Forest Service, Forest Products Laboratory (FPL), and Masonite Corporation.

In December 1994, hardboard siding from Masonite Corporation's Laurel, Mississippi, mill was installed on two test buildings in Delray Beach, Florida. The buildings were identical, except that one was constructed with 0.3-m (12-in.) overhangs without gutters and the other with gutters without overhangs. The siding boards were installed by an independent contractor's crew, following manufacturer's recommendations. Factory-finished and factory-primed (subsequently site-finished) boards were installed; half were back-primed and half were not, which resulted in four finishing treatments. The condition and thickness of the boards were recorded during site inspections every three months. Continuous monitoring of moisture content, temperature, and air pressure difference across the siding started in April 1995 and was terminated on May 5, 1997. The siding was removed and inspected in May 1997. We determined the final moisture content of the siding as well as that of the wood trim.

The siding used in this study had better moisture absorption and edge swell related properties than the minimum values required in the industry standard. This siding was statistically indistinguishable from other hardboard siding manufactured at the Laurel, Mississippi, plant between 1992 and 1995, but the data suggest that it had properties slightly better than the average for the other boards produced at that plant from 1992 to 1995. Our conclusions therefore cannot be extended to other hardboard siding without additional information about the properties of that siding.

The siding was in excellent condition after 2½ years of exposure to southern Florida weather. The moisture content of the siding remained at about 8% or lower, and in-place thickness swell of the siding was less than 3% during the entire exposure. There was no appreciable difference in lateral nail resistance between unexposed boards and siding that was on the building for 2½ years. There is no evidence that back-priming this siding lowered in-service moisture content. Siding on south-facing walls tended to be drier, but the type of wall construction or weather barrier had no detectable effect on moisture content of the siding.

There was no difference in siding moisture content between the two buildings. The moisture content of the trim, however, was generally lower on the overhang building. The overhangs also significantly reduced water leakage around windows. There was evidence of water leakage behind the window trim below more than half of the windows on the guttered building. The leakage occurred between the window unit and the bottom trim, even though the trim was carefully caulked with high-quality urethane caulk. In May 1997, the moisture content of the wood trim was generally between 9% and 12%, but we found several locations with moisture contents more than 20%. The leakage did not lead to decay of the siding or elevated siding moisture content. We found decay in a pine doorjamb on the guttered building.

The pressure data in this report indicate that conventionally installed lap siding allows for substantial air pressure equalization across the siding. The argument in favor of an air space behind the siding may still be valid but primarily because it probably provides better drainage of water that may penetrate to the back of the siding (especially around windows and doors). An air space would provide less opportunity for this water to penetrate the weather barrier and wet the sheathing. An air space may also increase the rate of drying.

There was evidence of air leakage past the top plate into the wall cavity. This air bypassed the weather barrier and created larger than expected air pressures across the gypsum board. This air leakage led to periods when the cavity was pressurized with respect to both the inside and outside. Finally, we found that wind-induced air pressures across the exterior walls were predominantly exfiltrative (that is, inside pressure higher than outside pressure), even on the windward side of the building.

Performance of Back-Primed and Factory-Finished Hardboard Lap Siding in Southern Florida

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Introduction

Performance problems with hardboard siding have been reported in southern Florida. Investigations have shown that most of these problems were due to improper installation or design, lack or deterioration of caulking, improper flashing, or lack of maintenance (HUD 1992) (Keplinger and Waldman 1988, unpublished data, available from HUD, Washington, DC). In response to these problems, the Department of Housing and Urban Development (HUD) promulgated a Local Acceptance Standard that requires prefinishing of the siding and priming of all surfaces (including the back surface). However, there was disagreement and uncertainty about the necessity and effectiveness of these measures. This study was aimed at resolving this uncertainty.

The goal of this 34-month project was to determine if back-priming or factory finishing improves the durability and performance of hardboard siding when installed according to recommended practice. The work was performed under a Sponsored Research and Development Agreement between the USDA Forest Service, Forest Products Laboratory (FPL), and Masonite Corporation.

Approach

Hardboard 0.2-m (8-in.) lap siding was installed on two test buildings in Delray Beach, Palm Beach County, in southern Florida. All siding was manufactured at Masonite Corporation's Laurel, Mississippi, mill. A large number of boards were instrumented and monitored for 2 years. There were four finish treatments consisting of combinations of back-primed versus not back-primed and factory prefinished versus site finished. The siding was exposed for approximately 29 months.

Temperatures, moisture contents (MCs), and time of wetting were monitored. In addition, information on wind and air pressures was collected to assess the potential for wetting by wind-driven rain. During regular site inspections, the condition of each board was noted and the thickness of the bottom edge was measured. Samples of the siding were used to determine linear expansion and residual thickness swell. At the time of siding removal, we cut a large number of samples and determined their final MC gravimetrically. At that time, we also thoroughly inspected the back of the siding as it was removed, as well as windows and other building details. We measured final MC of the trim with an electric moisture meter. The test buildings were demolished shortly after siding removal.

Siding Selection

All boards used in this study were provided by one manufacturer (Masonite Corporation) and came from a single mill (Laurel, Mississippi). To establish whether these boards were typical for boards manufactured at this mill, we compared our measurements of residual thickness swell, linear expansion, and lateral nail resistance to data from limited independent third-party random sampling and testing of siding produced from the same mill from 1992 through 1995. Our test procedures are described later in this report. The data are summarized in Table 1.

The siding used in this study, as well as the other siding manufactured at the plant, had properties that were substantially better than the minimum values required in the industry standard. The variation in the measured properties was such that the siding used in this study is statistically indistinguishable from the sample of boards manufactured at the same plant between 1992 and 1995. However, the data suggest that our siding had properties slightly better than the average for boards produced at that plant from 1992 to 1995.

Table 1—Comparison of test results on boards used in this study, test results on boards manufactured at the same mill (Laurel, Mississippi), and industry minimum standards

	Number of specimens						
	Residual swell	Linear expan-sion	Lateral nail resistance in machine direction	Lateral nail resistance in transverse direction	Residual swell[a], average (and range) (%)	Linear expan-sion[b], average (and range) (%)	Lateral nail resis-tance, average (and range) (kN [lb][c])
Boards used in this study, 1995	48	24	0	64	4.3 (1.6–7.4)	0.23 (0.21–0.27)	2.0 (1.6–2.3) [441 (360–518)][d]
Boards from Laurel mill, 1992[e]	3	3	9	9	6.0 (4.0–8.7)	0.24 0.25)	2.7 (2.6–2.8) [607 (585–621)]
Boards from Laurel mill, 1993[e]	3	3	9	9	3.6 (2.0–4.5)	0.32 (0.27–0.38)	2.2 (2.0–2.3) [503 (458–526)]
Boards from Laurel mill, 1994[e]	3	3	9	9	9.8 (5.0–13.2)	0.26 (0.24–0.30)	2.5 (2.4–2.7) [576 (546–598)]
Boards from Laurel mill, 1995[e]	4	4	12	12	6.2 (3.6–8.4)	0.23 (0.18–0.25)	2.0 (1.8–2.1) [455 (412–482)]
Industry standard[f]	Not specified	Not specified	Not specified	Not specified	20 maximum	0.40 maximum	0.67 minimum [150 minimum]

[a]Weatherability of substrate test.
[b]30% to 90% RH, machine direction.
[c]Data are for measurements in machine direction and transverse direction, except for FPL data, which were made in transverse direction only.
[d]FPL lateral nail tests were performed according to ASTM D1037 part A, with a 3.2-mm- (0.125-in.-) diameter pin. The other lateral nail tests were performed perpendicular to machine direction according to ANSI/AHA A135.6, with a 3.3-mm- (0.131-in.-) diameter pin. These differences make it difficult to directly compare FPL results with the other results.
[e]Test samples from the Laurel, Mississippi, mill were collected and tested by an independent third party.
[f]ANSI/AHA A135.6-1990 minimum requirements.

Table 2—Equilibrium moisture content (EMC) at different relative humidity (RH) levels

RH (%)	EMC of hardboard siding[a] (%)	EMC of southern pine[b] (%)	EMC of construction plywood[b] (%)
30	3.9	5.3	4.8
43	4.7	7.0	6.3
65	6.8	10.8	9.7
79	8.9	14.8	13.4
90	10.4	20.0	18.5

[a]Sorption only.
[b]Richards and others (1992).

We measured equilibrium moisture content (EMC) of the hardboard siding (Table 2). The siding had lower EMC than solid wood or plywood at corresponding relative humidity (RH) conditions. Values for hardboard in Table 2 are in general agreement with previously published values (Bristow and Back 1969) for heat-treated hardboards.

Building Construction

One building was built with 0.3-m (12-in.) overhangs, including the gable ends, but without gutters (the overhang building; walls in this building are designated with an O). The other building was built without overhangs but with gutters (the guttered building; walls in this building are designated with a G) (Figs. 1 and 2). The buildings were identical in all other construction details. Dimensions of the buildings were 9.8 by 9.8 m (32 by 32 ft) with a slab-on-grade foundation. The top of the slab was about 0.10 to 0.15 m (4 to 6 in.) above grade. The buildings had balloon-framed gable ends with a 4/12 pitch roof with asphalt shingles. The rest of the roof was framed with standard roof trusses. One gable end faced NNE (35° from north). The attic of each building was vented with gable end louvers, and the attic of the overhang building received additional venting from perforated aluminum soffits. Ceilings and exterior

Figure 1—Test building with overhang (foreground) and test building with gutters (background).

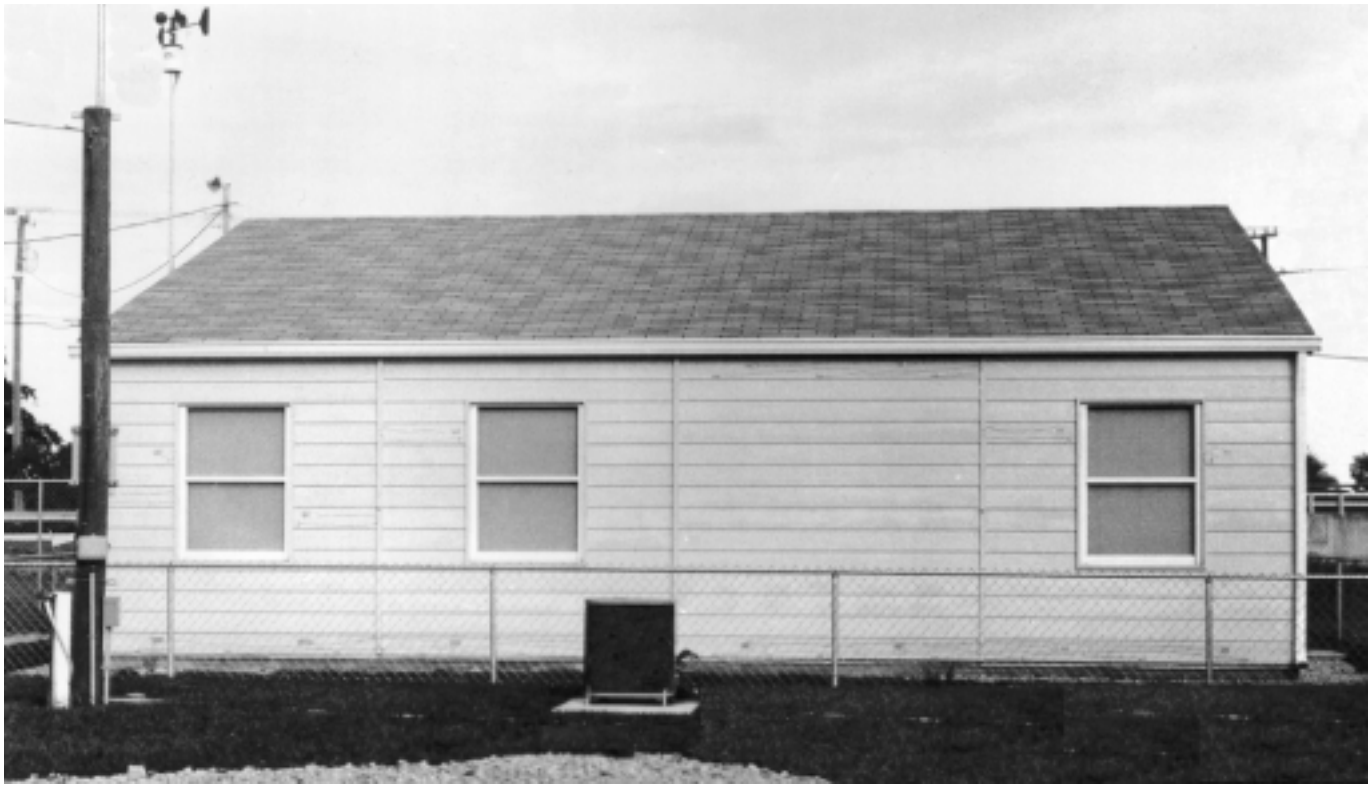

Figure 2—Test building with gutters (side view).

walls were insulated with fiberglass batt insulation (unfaced in the walls, faced in the ceiling). The buildings had interior electrical wiring, phone service, and air ducts for distribution of cooled air, with ceiling fans for additional air distribution. The air ducts were within the conditioned interior (that is, not in the attic), and there was no evidence that the air conditioner or distribution system pressurized or depressurized the interior to any significant degree.

Wall Construction

The walls were wood-framed, standard 38- by 89-mm (nominal 2- by 4-in.) construction. For both buildings, each side of the building was divided into four wall sections, designated a, b, c, and d. Three different wall construction techniques were used on each building:

- no sheathing, 15-lb felt building paper (OF);
- plywood sheathing (0.5-in. CDX), 15-lb felt (PF)
- plywood sheathing, woven polyolefin (Barricade, Simplex Products Division, Adrian, Michigan) (PT)

Each wall section was 2.4 m (8 ft) long. Adjacent wall sections were separated with a chromated copper arsenate (CCA)-treated pine standard 38- by 140-mm (nominal 2- by 6-in.) stud sandwiched between the end studs of the wall sections, except at the corners. The outside face of the treated 2 by 6 separator protruded beyond the face of the siding as can be seen in Figure 2. The separators (or air dams) prevented air movement behind the siding between wall sections. The outside corner walls were joined with standard vertical outside-corner trim consisting of western redcedar strips (Fig. 2). Wall framing was installed so that the outside surface of siding was flush; on wall sections without plywood sheathing, this was achieved by moving the framing outward by 13 mm (0.5 in.). Wall construction on the gable ends was identical to that of the wall sections directly below.

Two doors and twelve windows were installed in each building. The doors were prehung steel-door units with pine (not pressure treated) jambs. Exterior trim for these units was site-fabricated from western redcedar strips. The windows were aluminum single-hung (lower sash sliding vertically) units with side nailing flanges (the top and bottom flanges were narrow and unsuitable for fastening the units in place). These were installed over the sheathing or framing, sometimes in a bed of caulk. The weather barrier (felt or polyolefin) was applied after window installation, generally over the side flanges, but just missing the narrow top and bottom flanges; in some cases, the weather barrier below the window was caulked to the framing or sheathing. Rectangular trim units were site-fabricated from western redcedar, which were then installed over the flanges. The piece of cedar at the bottom of the trim unit was sloped to the exterior. The trim unit was caulked to the window unit with urethane caulk.

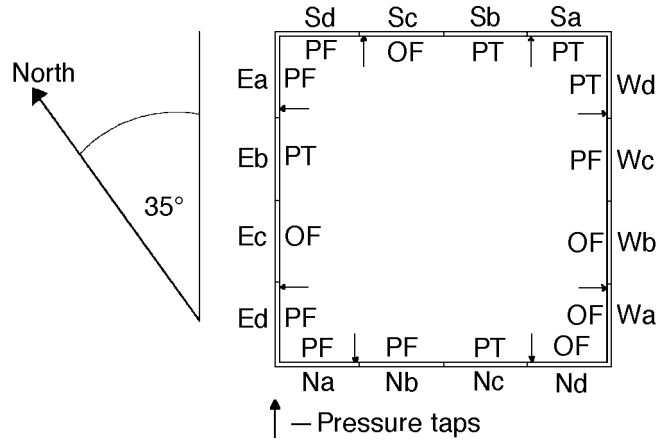

Figure 3—Orientation of test buildings, with wall construction type and location of pressure taps (N, S, E, W designate direction; a, b, c, d designate wall section; PF, plywood sheathing with felt; OF, felt without sheathing; PT, plywood sheathing with polyolefin weather barrier).

Joints in the trim unit were also caulked. Aluminum head flashing was installed over the top cedar trim piece above all window and door units. An additional sheet of weather barrier was installed over the upper leg of the aluminum head flashing.

Figure 3 shows the orientation of the buildings, designation given to each wall section, and distribution of construction types around the building. As built, the buildings were rotated 180 degrees relative to the orientation specified in the plans. Thus, wall sections designated N actually faced southwest, sections designated S faced northeast, sections designated E faced northwest, and sections designated W faced southeast.

Siding Finishes

All siding was embossed Masonite 0.2-m (8-in.) hardboard lap siding. All siding was factory-primed on the front side. Topcoat finishes were factory-applied or applied on-site. FPL personnel primed the back surface of roughly half the boards with an oil-based primer in an unconditioned warehouse in Delray Beach about 2 months prior to installation. The primer spread rate was 7.6 m^2/L (308 ft^2/gallon). The rest of the boards were left unprimed, although all siding had some incidental paint on the back side, which was how it was received from the mill. The following siding finishing combinations were installed:

- back-primed, factory finished (BF)
- not back-primed, factory finished (NF)
- back-primed, site finished (two coats) (BS)
- not back-primed, site finished (two coats) (NS)

Site-applied finish was applied within 10 days of siding installation. Wet application weight of site-applied finish averaged approximately 190 g/m^2 (0.039 lb/ft^2). This was equivalent to a spread rate of approximately 6.6 m^2/L (270 ft^2/gallon) of paint. We used Porter Paint (Louisville, Kentucky) acrylic gloss exterior paint, applied by brush by a professional painter. The paint color was similar to that of the factory-finished siding. Care was taken that good coverage was obtained, and a mirror was used to inspect the drip edge to ensure full coverage.

Siding Installation and Trim

The siding was installed on the test buildings during the last week of November and first two weeks of December 1994. The guttered building was sided first. The contractor's carpenter crew installed the siding, but instrumented boards were installed under the direction and with assistance of FPL personnel. Siding was face-nailed with hand-driven galvanized nails. Any damage from installation was repaired. The minimum overlap between boards was 25.4 mm (1 in.). Siding crosscuts were left unpainted, and their location on the building was marked (uncut primed edges are marked P in Figs. 4–11). Joints between separators and siding were caulked with urethane caulk. (The detail resembled a standard inside corner detail.) Window, door, and outside-corner trim were installed before the siding. All joints between siding and trim were caulked with urethane caulk. Gable end cuts of the siding were protected from the weather. On the overhang building, they were covered by aluminum soffit, and on the guttered building, they were covered with redcedar gable end trim. The metal roof edge covered the top edge of the gable end trim; the gable end trim was slid up under the roof edge and nailed in place. The drip edge of the bottom siding course was about 0.10 to 0.15 m (4 to 6 in.) above grade and had a metal termite shield below it.

The four different combinations of siding finish treatments were alternated vertically. A different treatment was used on the bottom of each wall section, and the same sequence was used moving up. This sequence is shown in Table 3. Table 4 shows which types of boards were installed as bottom boards in which wall unit.

As siding pieces were installed, end-cut pieces were saved for determining siding MC as installed. Disks were cut from these pieces with a hole saw, loose fibers were removed by sanding, and the disks were weighed on a digital balance. The disks were transported to FPL, ovendried, and again weighed with a digital balance. Moisture content of all specimens at installation ranged between 5% and 7% (Fig. 12). Back-primed specimens were consistently somewhat drier at the time of installation; all were under 6% MC.

Instrumented Siding Boards

A total of 46 siding boards were monitored on each building. These boards were placed in strategic locations to represent a variety of exposures. Placement was identical on both buildings, except for two short boards that had been cut too short for their intended location on the guttered building. These two boards were moved to other locations on the same or adjacent wall section. Most instrumented boards were located in potential moisture stress locations. Potential moisture stress locations were abutting a window or door, bottom of wall (backsplashing of rainwater), and top of sidewalls.

Boards at the bottom and top of the wall ran the full width of the wall section (2.4 m (8 ft)), whereas the boards abutting windows and doors were considerably shorter. Instrumented boards were distributed around the building as follows (Fig. 4–11):

- Gable ends (total of 12 sites per wall)
    - 6 window sites (short)
    - 2 door sites (short)
    - 2 bottom sites (long)
    - 2 top sites (long)
- Sidewalls (total of 11 sites per wall)
    - 6 window sites (short)
    - 4 bottom sites (long)
    - 1 top site (long)

The distribution of instrumented boards was such that all board finish combinations were represented on each side of the building, the distribution of board finish combinations by type of site (window–door, top, or bottom) was as even as possible, and the distribution of board finish combinations by type of wall construction was as even as possible.

Interior Conditions

Interior conditions were selected to simulate a typical southern Florida home environment. The thermostats controlling the air conditioners in both buildings were set at 24°C (75°F). Measurements indicate that the guttered building actually was maintained between 25°C and 28°C (77°F and 82°F), and the overhang building between 22°C and 26°C (72°F and 79°F). Because the buildings were unheated, indoor temperature was uncontrolled for short periods during winter. Indoor RH was maintained at 50% with humidistat-controlled humidifiers. Water for the humidifiers was obtained from the air conditioner drip pans. Excess water from the drip pans was drained to the outside through sub-slab drains. Humidity occasionally rose above 50% during winter periods when the air-conditioners did not run.

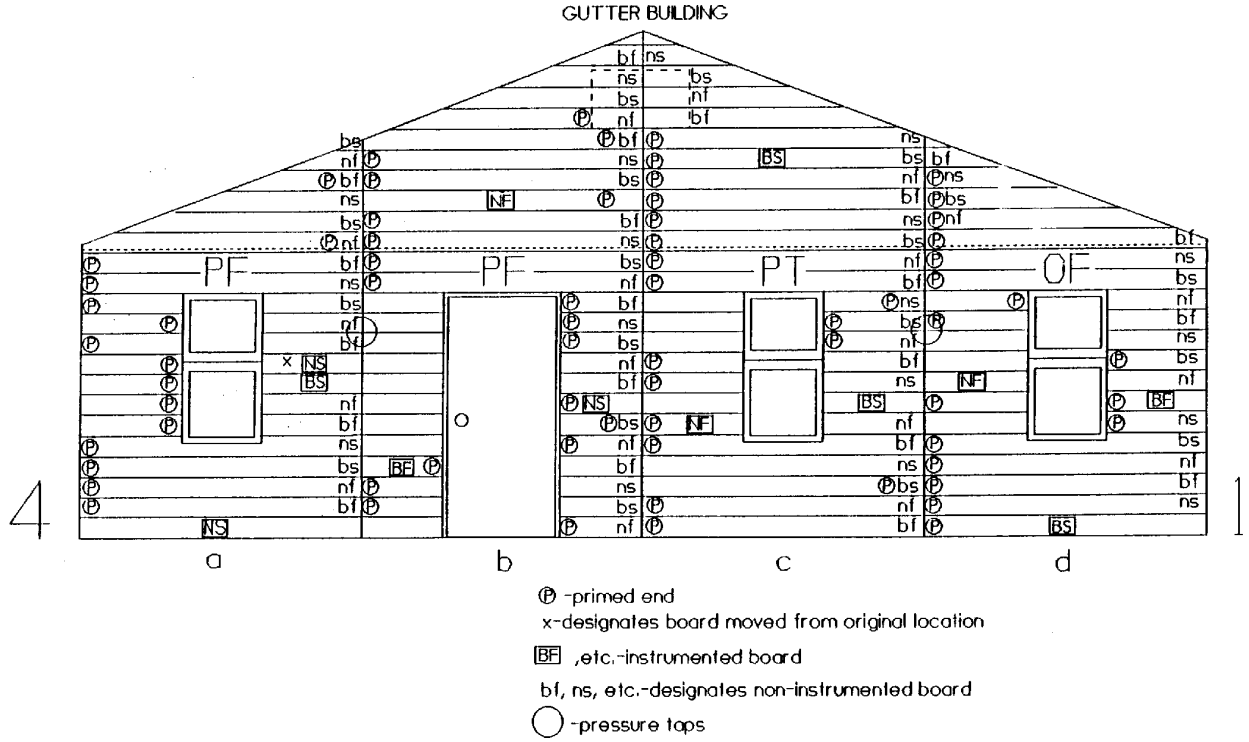

Figure 4—Overall layout of southwest-facing wall (wall sections GNa–GNd) of guttered building.

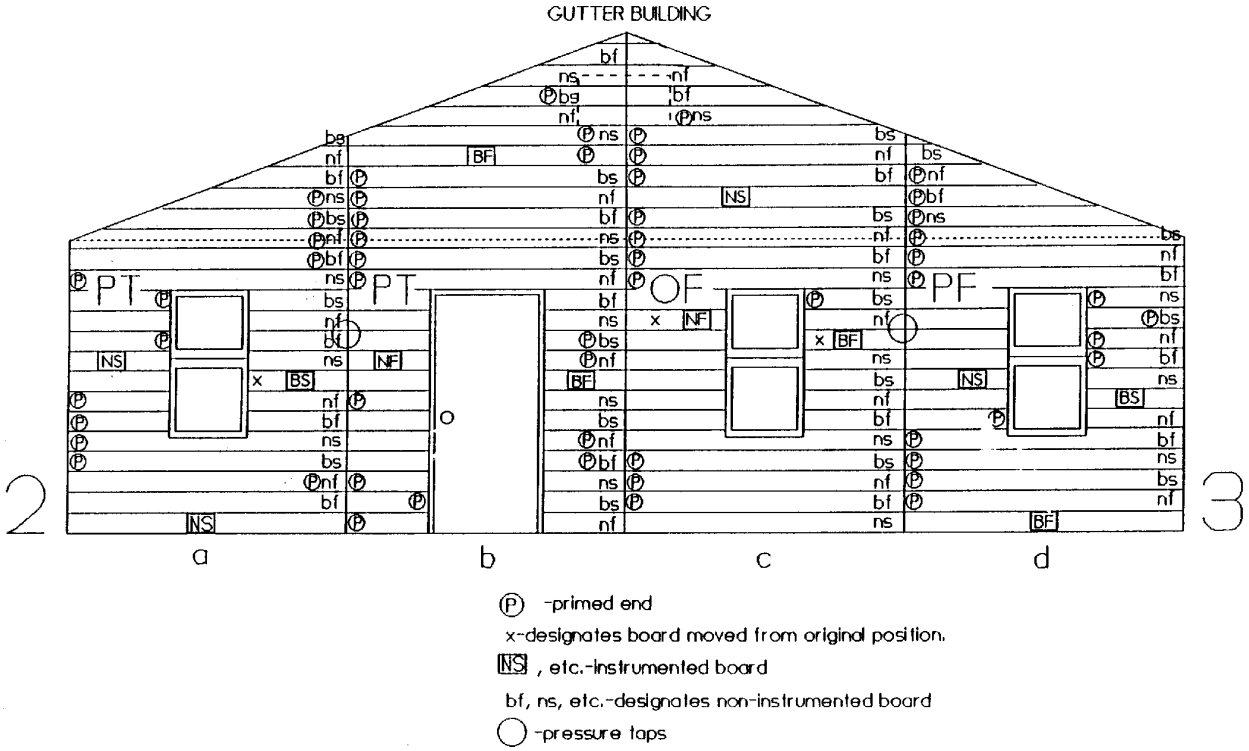

Figure 5—Overall layout of northeast-facing wall (wall sections GSa–GSd) of guttered building.

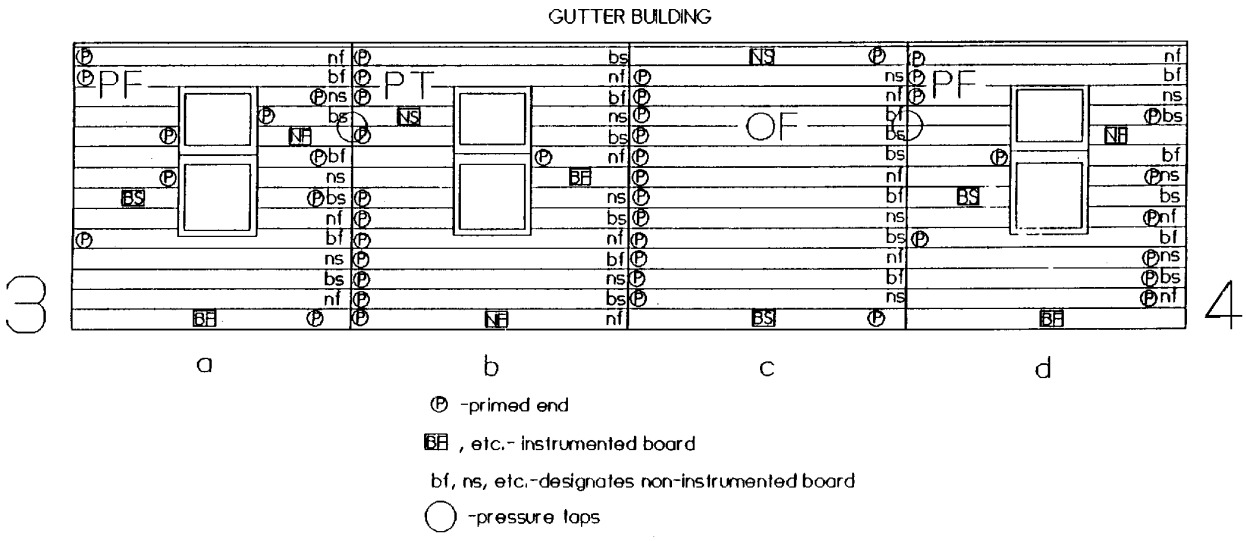

Figure 6—Overall layout of northwest-facing wall (wall sections GEa–GEd) of guttered building.

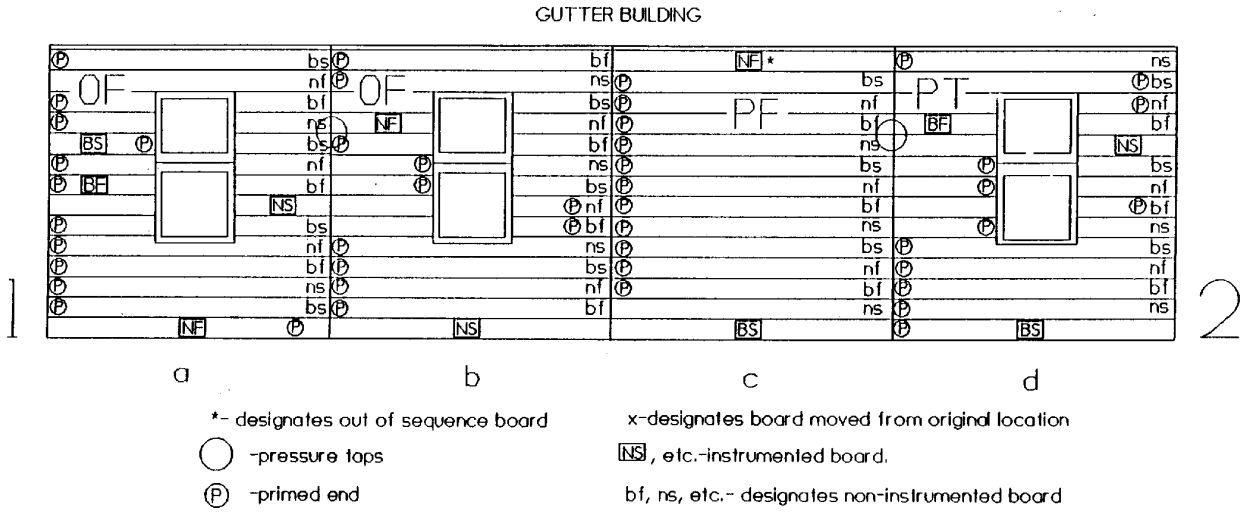

Figure 7—Overall layout of southeast-facing wall (wall sections GWa–GWd) of guttered building.

Instrumentation and Data Acquisition

The instrumentation monitored the following parameters on an hourly basis:

- moisture content of the siding
- time of wetness (presence of liquid water on surface), front and back of the siding
- temperature of siding
- outdoor temperature and RH
- indoor temperature and RH
- wind speed
- wind direction
- humidifier run-time
- humidifier water supply status

Full-length siding boards (18 per building) had the following sensors (Fig. 13):

- 2 thermocouples
- 3 pairs of MC pins
- 4 time-of-wetness (TOW) sensors (2 on the front, 2 on the back surface)

Short boards (next to windows and doors, 28 per building) had the following sensors (Fig. 13):

- 1 thermocouple
- 1 pair of MC pins
- 2 TOW sensors (1 on the front, 1 on the back surface)

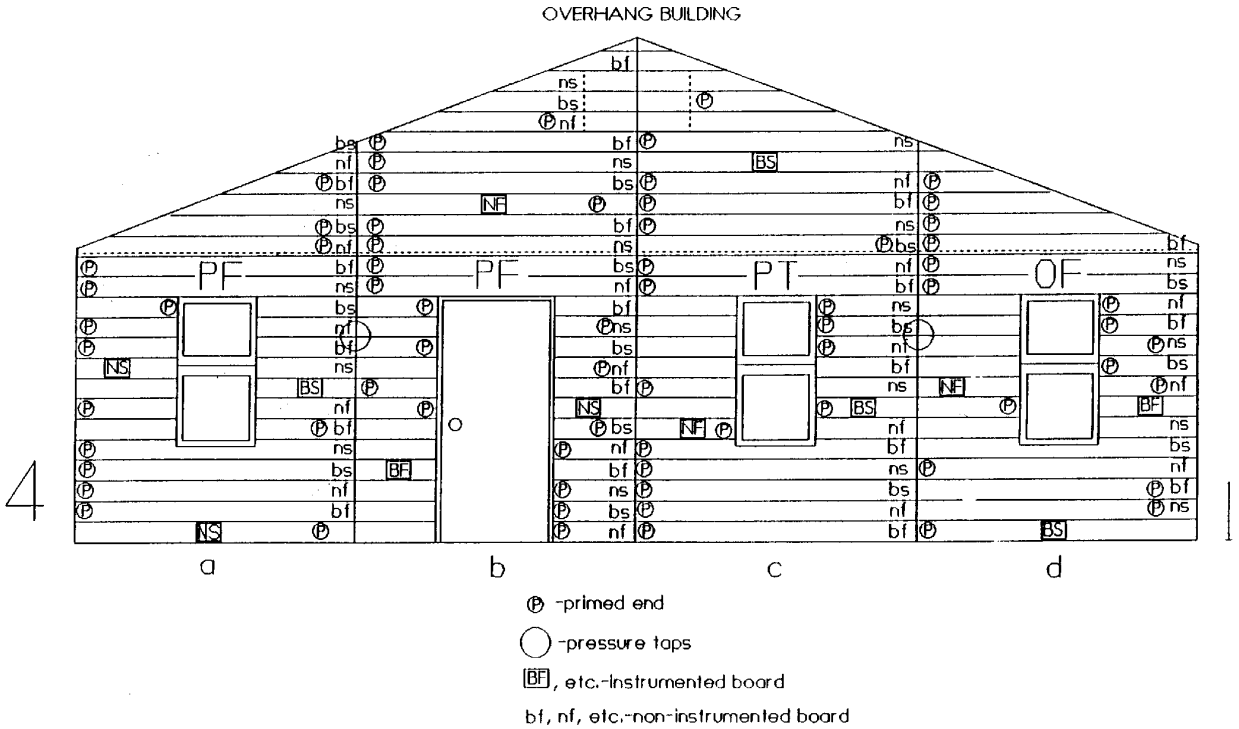

Figure 8—Overall layout of southwest-facing wall (wall sections ONa–ONd) of overhang building.

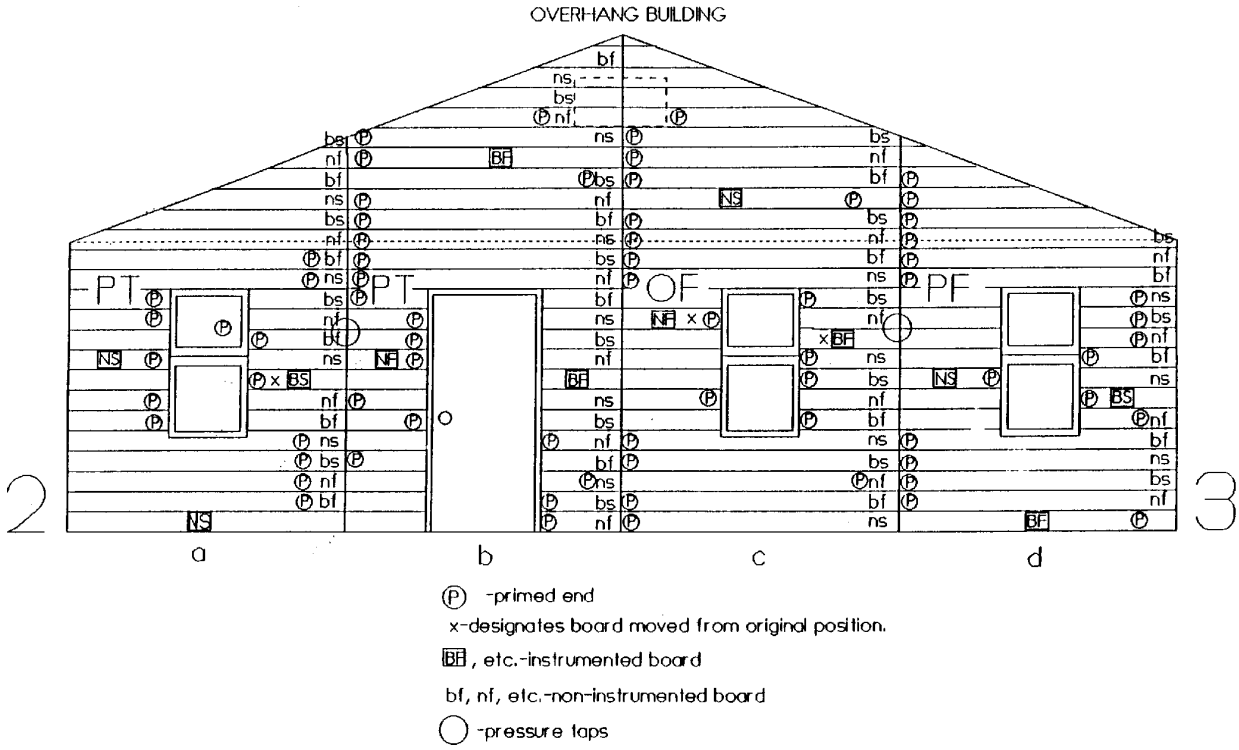

Figure 9—Overall layout of northeast-facing wall (wall sections OSa–OSd) of overhang building.

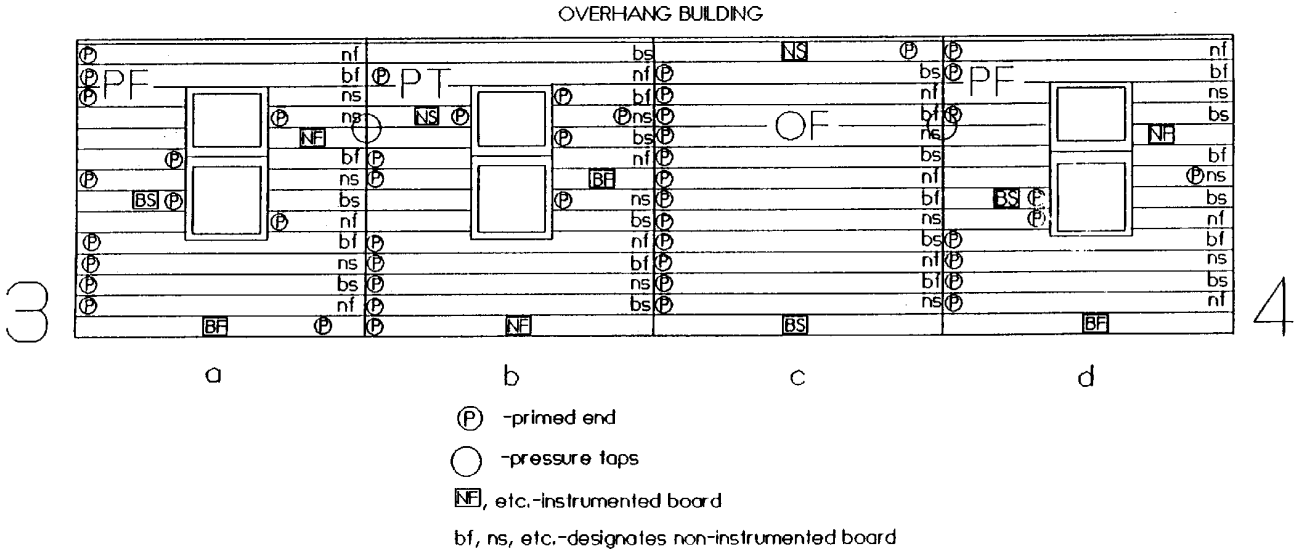

Figure 10—Overall layout of northwest-facing wall (wall sections OEa–OEd) of overhang building.

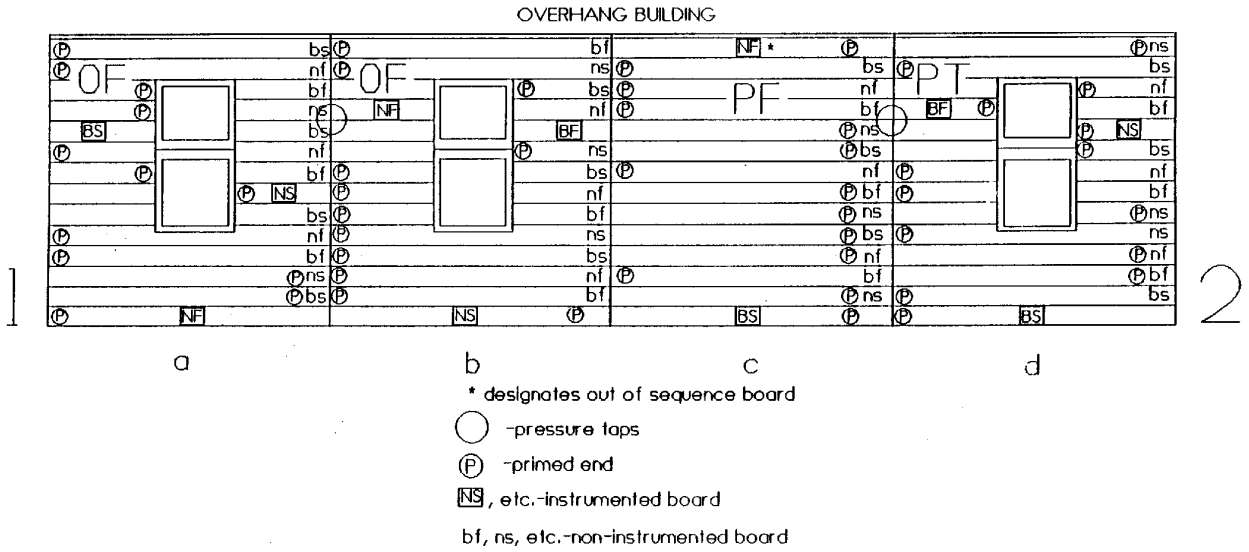

Figure 11—Overall layout of southeast-facing wall (wall sections OWa–OWd) of overhang building.

The total numbers of sensors per building were as follows:

- 64 thermocouples
- 82 pairs of MC pins
- 128 TOW sensors
- 1 weather station (temperature and RH)
- 1 indoor RH and temperature sensor

Type T thermocouples were embedded in the boards, through holes drilled from the back of the board. After installation, the holes were caulked. Thermocouples were connected directly to a computer data acquisition card.

The insulated MC pins were installed in predrilled holes and carefully caulked to prevent water entry into the holes. After attachment of the leads, the pins were covered with silicone and urethane caulking for protection from the rain. The pins were calibrated at FPL for the specific siding used in this study. Calibration was achieved by preconditioning the hardboard at various MCs, measuring MC with pins, and then determining actual MC gravimetrically. Leads were connected to linear amplifiers, which in turn fed into computer data acquisition cards.

The Forest Products Laboratory developed TOW sensors especially for this study. The TOW sensors indicate when

Table 3—Sequence of siding boards, by treatment, as installed on the buildings starting from the bottom[a]

Back-priming	Finish	Code
Yes	Site	BS
No	Site	NS
Yes	Factory	BF
No	Factory	NF

[a]The board used to start at the bottom of each wall varied, but the sequence moving up the wall was the same.

Table 4—Type and location of bottom starting siding boards in each wall

Wall	Wall section	Board type	Instrumented
Southwest	Na	NS	Yes
Southwest	Nb	NF	No
Southwest	Nc	BF	No
Southwest	Nd	BS	Yes
Southeast	Wa	NF	Yes
Southeast	Wb	NS	Yes
Southeast	Wc	BS	Yes
Southeast	Wd	BS	Yes
Northeast	Sa	NS	Yes
Northeast	Sb	NF	No
Northeast	Sc	NS	No
Northeast	Sd	BF	Yes
Northwest	Ea	BF	Yes
Northwest	Eb	NF	Yes
Northwest	Ec	BS	Yes
Northwest	Ed	BF	Yes

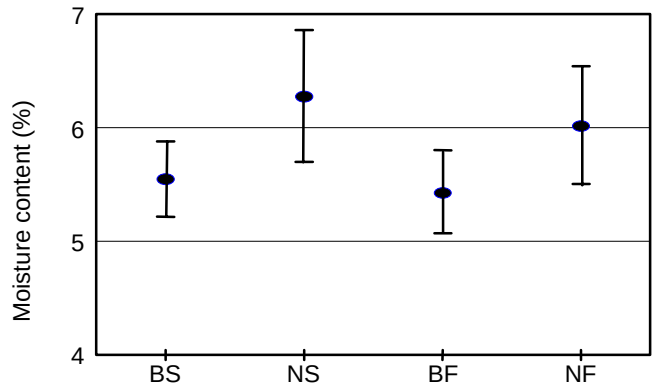

Figure 12—Initial moisture content of the siding at time of installation, by finish type.

the surface is wet, either from rain or dew. The sensor consisted of a pair of parallel lead alloy foil strips that were attached to the surface. Each strip was approximately 10 by 51 mm (3/8 by 2 in.), and the distance between the strips was approximately 0.4 mm (1/64 in.). Connection wires, attached to each strip with silver solder epoxy, connected the TOW sensor to an oscillating circuit. When liquid water between the two strips reduced the electric resistance between the strips below a critical value, the oscillating circuit produced a signal that was recorded hourly with the data acquisition system. The TOW sensors were placed on the front and back surface of instrumented boards. The strips on the front surface were placed horizontally at mid-height (Fig. 13). Foil strips on the back surface were oriented vertically, with the lower ends of the strips ending 13 mm (0.5 in.) above the drip edge so that there would be at least 13 mm (0.5 in.) of sensor in the siding overlap (Fig. 13). In October 1996, we checked the TOWs on the exterior surface by spraying them with water. The TOWs that were not functioning were disconnected. The TOWs on the back surface of the siding

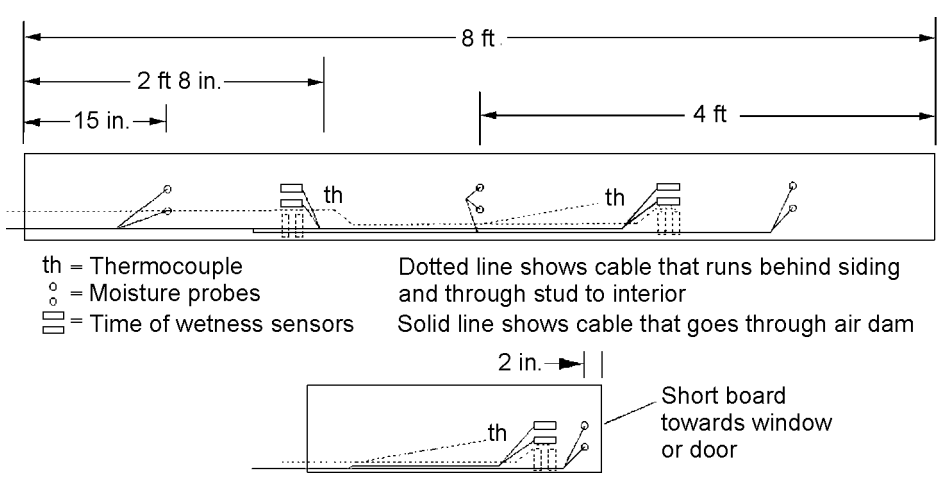

Figure 13—Location of instrumentation on instrumented boards on full-length and short boards (1 ft = 0.3048 m, 1 in. = 25.4 mm).

that we suspected of malfunctioning were checked in a similar manner in May 1997, just before removal of the siding. However, testing of the TOW sensors in the laboratory in high RH and temperature after the conclusion of monitoring revealed that some TOW sensors registered "wet" at high RH without the presence of liquid water. We therefore cannot trust the data from the TOW to always indicate liquid water and decided to reject the data. However, we have since found a method to avoid the problem of false positive readings and intend to use this sensor in the future.

Air pressure differences across the siding were monitored continuously at eight locations on each building. The location of the pressure taps is indicated in Figure 3. The pressure tubes were installed at mid-height of the wall section (that is, approximately 4 ft (1.2 m) from the ground), which minimized the inclusion of any stack effect in the pressure readings. Pressure at each location was measured with an individual differential pressure sensor, which had a range of ±200 Pa with a resolution of 0.1 Pa (1 Pa = 1.45×10^{-4} lb/in^2). The zero-pressure offset was recalibrated every hour. Pressure differences were recorded continuously every 5 s, with pressure data collection suspended for roughly 5 min each hour for reading MC pin, TOW, and thermocouple data (the computer in the guttered building also collected wind speed and direction data). The detailed pressure data were usually discarded every hour after an hourly average, maximum, minimum, and standard deviation were computed for each pressure tap. However, we instructed the computer by phone several times to store and transmit the detailed pressure data. During the early months of data collection, we experienced problems with insects blocking pressure tubes and with malfunction of the pressure sensor hardware. After these problems were corrected, reliable pressure data were collected on the guttered building starting mid-September 1995 and on the overhang building starting early February 1996. On October 8, 1996, the pressure tap configuration in the overhang building was changed as shown in Table 5. This change allowed us a more detailed look at the pressures inside the cavities and pressures across the entire wall of wall sections OWd and ONa. Many of these data were collected at 15-s intervals. The pressure taps in the guttered building were left unchanged.

Hourly wind speed and direction data were collected starting in the middle of September 1995. The orientation of the wind vane was verified at the time of installation by the position of the sun at local solar noon. Both wind speed and direction were recorded as 10-min averages at the beginning of each hour. Instantaneous direction at the end of each 10-min period was also collected. On March 2, 1996, the wind vane failed, and on June 20, the anemometer also failed. No reliable wind speed and direction data were received between June and early October, when a new wind measurement system was installed.

All hourly and wind data were collected and stored on a personal computer (one for each building) and transferred automatically to FPL in Madison, Wisconsin, by phone each day. The data acquisition system was installed and activated in February 1995. After some adjustments and corrections were made, data acquisition officially commenced on May 1, 1995, and ended on May 6, 1997.

Table 5—Pressure tap configuration in overhang building before and after changes in configuration on October 8, 1996

Sensor number	Pressure before October 8, 1996	Pressure after October 8, 1996
1	Across siding of wall ONd	Between cavity and outside, wall ONa
2	Across siding of wall OWa	Across entire wall OWd
3	Across siding of wall OWd	Unchanged
4	Across siding of wall OSa	Between cavity and outside, wall OWd
5	Across siding of wall OSc	Unchanged
6	Across siding of wall OEa	Unchanged
7	Across siding of wall OEd	Across entire wall ONa
8	Across siding of wall ONa	Unchanged

Precipitation was measured manually with an on-site rain gauge, generally at weekly intervals. These data were periodically mailed to FPL.

Site Inspections

The siding condition was visually inspected every 3 months. Thickness of the lower left and right edges of each siding board was measured in-place during each visit, using a specially designed tool (Fig. 14). At each inspection, photographs were taken to document any visual changes in the siding. In total, 10 site inspections were performed between December 1994 and May 1997. The last inspection took place just before the siding was removed in May 1997.

Siding Removal

On May 5 and 6, 1997, prior to removal of the siding, we measured the MC of all wood trim, except the fascia of the guttered building, with an electric resistance moisture meter. On May 6 to 9, 1997, the siding was removed and visually inspected. Water stains were noted and photographs taken. For each building, we cut and weighed 128 0.2-m- (8-in.-) wide siding specimens (eight per wall section) for MC determination. However, three specimens were lost, so we ended up with 126 samples from the guttered building and 127 samples from the overhang building. The samples were ovendried at FPL and weighed again to determine MC. In addition, we cut three 25-mm (1-in.) horizontal slices from ten 0.10-m- (4-in.-) wide samples for determining vertical MC gradients. An additional sixty-four 0.08-m- (3-in.-) wide specimens (four per wall section) were collected from each

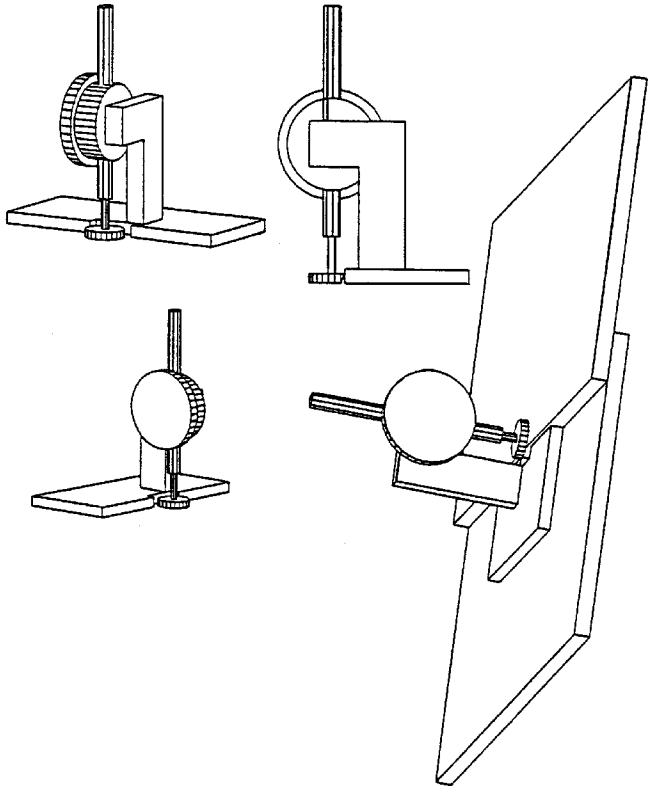

Figure 14—Thickness measurement device.

building for measuring lateral nail resistance. We also cut several circular specimens out of the plywood sheathing for MC determination. On May 9, we opened the Na and Wd wall sections of the overhang building for inspection. These were the wall sections for which we collected detailed air pressure data. Finally, two windows from each building (one from the southwest-facing wall and one from the northeast-facing wall) were cut out of the wall and removed with the wall sections attached for later disassembly and inspection.

Laboratory Measurements

Linear Expansion

In early November 1994, samples from the lot of siding used on the buildings were selected by FPL personnel and transported from Delray Beach to FPL in Madison for determining linear expansion (LE) characteristics. These were kept in storage until late spring of 1995, at which time LE measurements were made in general accordance with sections 107 to 110 of ASTM D 1037 (ASTM 1996). Deviations from D 1037 were as follows: (a) linear expansion was measured between equilibrium at 30% and 90% RH as specified in ANSI/AHA A135.6-1990 (AHA 1990), (b) temperature at each of these conditions was 26.7°C (80°F) rather than 21.9°C (70°F), and (c) measurement was made across 0.25 m (10 in.).

The device used to measure length consisted of two magnifying eyepieces with crosshairs and a traveling stage equipped with a linear variable differential transducer (LVDT) with digital readout. Reference marks were placed on the specimen by placing scratch marks on the heads of short brass pins that were driven into predrilled holes approximately 0.25 m (10 in.) apart. Test specimens were placed on the traveling stage and weighted with a lead weight to prevent movement of the specimen relative to the stage. A measurement was made by adjusting the stage until one of the crosshairs lined up with one of the scratch marks, zeroing the LVDT, then moving the stage until the other crosshair lined up with the other scratch mark, and reading the stage movement from the digital readout.

There were 24 linear expansion specimens, six specimens from each of the four finish treatments (NF, BF, NS, and BS). Because the sample boards were collected prior to installation (and thus prior to site finishing), specimens representing treatments NS and BS did not actually have a finish topcoat. Within each finish treatment, specimens were selected at random. With the room maintained at 30% RH, the specimens rapidly reached equilibrium after which the first set of measurements was made. With the room maintained at 90% RH, time to reach equilibrium was substantially longer, and measurements were made after weight gain from vapor sorption became negligible. Specimens were weighed at both equilibrium conditions. After the LE measurements were completed, specimens were ovendried and MCs at each RH condition were determined.

Residual Thickness Swell

From the same sample boards transported from Delray Beach to FPL in early November 1994, specimens were prepared and tested for residual thickness swelling as per section 4.1 of ANSI/AHA A135.6-1990 (Weatherability of Substrate). Tests were performed during the summer of 1995. Forty-eight specimens were tested, 12 randomly selected specimens from each of the four finish treatments. As with linear expansion tests, specimens representing treatments NS and BS did not actually have a finish topcoat. Because of size limitations of the soaking tank, the specimens were tested in two batches, with 24 specimens in each batch.

Deionized water was used in the soak tank. The tank was equipped with a float valve to maintain 25-mm (1-in.) immersion depth of the lower edge during the 18.5 h of soaking. Immersion depth was checked roughly 7 h into each soak period, with readjustment of the float valve made as necessary. Immersion level and water temperature were maintained within the limits specified in ANSI/AHA A135.6–1990. The only minor deviations from the ANSI/AHA specifications occurred when cycling was stopped during the weekend after the fourth or fifth cycle and when samples were stickered at ambient temperature during the weekend rather than put in a plastic bag, as

specified in the ANSI/AHA standard. We believe that these slight irregularities were unlikely to appreciably affect the results.

Lateral Nail Resistance

We performed lateral nail resistance (LNR) tests to determine if exposure on the test buildings changed the resistance of the boards to lateral nail movement. We speculated that the drip edge was probably more subject to degradation than any other part of the panel, and therefore, we performed LNR tests near the drip edge. The standard procedure for performing this test is outlined in sections 41 to 46 of ASTM D 1037. We used ASTM D 1037 procedures for our tests, with the following exceptions: (a) We used a tempered high carbon steel pin of 3.2-mm (0.125-in.) diameter rather than a common 6d nail, because of the tendency of the 6d nail to bend when testing hardboard (see Note 17 of ASTM D 1037). (b) All specimens were tested with the loading stress perpendicular to the long dimension of the siding boards (so as to pull the pin downward towards the drip edge). ASTM D 1037 stipulates that half of the test specimens be tested in this direction and half in the perpendicular direction to determine whether the boards have directional properties. (c) We did not test any specimens in the soaked condition.

Our test procedure was also slightly different from the procedure described in Standard ANSI/AHA A135.6 for lateral nail tests for hardboard siding. The ANSI/AHA procedure is based on ASTM D 1037 but prescribes an 8d nail (3.3-mm or 0.131-in. diameter) rather than a 6d nail (2.9-mm or 0.113-in. diameter) and a loading speed of 3.2 to 4.4 mm/min (0.125 to 0.175 in/min) rather than 6.4 mm/min (0.25 in/min). These differences make it difficult to compare our results with those produced according to ANSI/AHA.

Test specimens were conditioned to equilibrium at 23°C (74°F) and 65% RH prior to test. Tests were done at pin spacing (from panel edge) of 6, 9, and 12 mm (1/4, 3/8, and 1/2 in.). Three test specimens were cut from each of 193 larger samples to provide one specimen for each test. In this manner, we collected three sets of 64 specimens from each of the buildings, plus three sets of 64 specimens from unexposed boards. The specimens represented each of the finishing treatments (BF, BS, NF, and NS) from each of the 16 wall sections. Inadvertently, we collected and tested an additional three BS specimens from the overhang building and lost a specimen from the unexposed boards, ending up with LNR measurements for 578 specimens (191 unexposed, 192 from guttered building, and 195 from overhang building). Lastly, we found (after testing, tallying, and inspection) that the finish system on the 11th course of wall section OEa on the overhang building was NS rather than BS.

Results From Inspections and Measurements During Siding Removal, May 1997

Visual Inspection

In general, we found the siding to be in excellent condition. We did not notice any decay of the siding, edge swell, or paint failures. In some more shaded locations on the buildings, some mildew was apparent on the siding and wood trim.

We found water stains on the back of siding below at least half of the windows on the guttered building. In contrast, on the overhang building, we did not see any staining of siding below windows. On the guttered building, stained siding backs were observed below windows in walls GNa, GNc, GNd, GSc, GWa, and GWd. Another two windows (GEb and GWb) may also have leaked. Water leakage apparently occurred between the window unit and the bottom trim or lower portions of side trim. This occurred despite careful caulking with high quality urethane caulk. Caulk adhesion failed at some wood–wood joints (trim) and at some wood–metal joints (window), which led to the window water leakage. Although the water stains on siding backs indicated that water leakage into the siding system had occurred, there was no evidence of damage to the siding. Tracing of stains across the backs of successive siding courses indicated that the water eventually drained to the front of the siding or evaporated.

Four windows (ONc, OSc, GNc, and GSc) were completely removed from the buildings, including the adjacent wall assembly, and were shipped to Masonite's West Chicago, Illinois, laboratory for disassembly. Evidence was found of leakage behind the weather barrier on window ONc (overhang building) and GNc (guttered building). The plywood sheathing below window GNc was severely discolored and perhaps would have decayed in several years. The staining of the plywood under window ONc was less severe. Window trim in the lower left corner of window GSc was discolored. Window OSc showed no signs of leakage or deterioration. Only four windows were inspected in this fashion, so this type of leakage or deterioration may have gone undetected on other windows where we did not remove the weather barrier.

We found decay in the lower jamb of the door in wall GNb (guttered building) but not in any other doorjambs or trim.

Final Moisture Content of Siding

We gravimetrically determined the MC of samples cut from the siding at the time of siding removal (May 1997). The 126 samples from the guttered building varied between 5% and 8% MC, with an average MC of 6.4%. This corresponds with an equilibrium MC at RH between 60% and 70% (Table 2). The 127 samples from the overhang building also

Table 6—Average moisture content (MC) of siding at the time of removal from building, by finish treatment type, wall construction, and orientation

Finish treatment or wall construction type[a]	Average MC (%) [standard deviation (%)/number of specimens]				
	East (northwest)	North (southwest)	South (northeast)	West (southeast)	All
Guttered building					
BF boards	7.16 [0.22/8]	6.11 [0.35/8]	7.71 [0.16/8]	5.96 [0.24/9]	6.71 [0.77/33]
BS boards	6.99 [0.30/8]	6.00 [0.34/8]	7.71 [0.24/7]	5.96 [0.33/7]	6.65 [0.78/30]
NF boards	6.14 [0.23/7]	5.63 [0.52/9]	7.20 [0.40/8]	5.72 [0.82/8]	6.10 [0.76/32]
NS boards	6.20 [0.47/9]	5.44 [0.38/7]	7.00 [0.16/8]	5.60 [0.74/7]	6.06 [0.77/31]
PF walls	6.61 [0.48/16]	5.84 [0.35/16]	7.31 [0.33/7]	5.62 [0.29/8]	—
PT walls	6.89 [0.51/8]	6.16 [0.43/8]	7.41 [0.46/16]	6.38 [0.58/8]	—
OF walls	6.39 [0.64/8]	5.36 [0.42/8]	7.23 [0.43/8]	5.53 [0.47/15]	—
All	6.62 [0.56/32]	5.80 [0.48/32]	7.35 [0.41/31]	5.77 [0.59/31]	6.38 [0.83/126]
Overhang building					
BF boards	7.14 [0.33/8]	6.28 [0.24/8]	7.56 [0.17/8]	6.21 [0.27/8]	6.80 [0.63/32]
BS boards	6.93 [0.18/7]	6.09 [0.28/7]	7.34 [0.17/8]	6.05 [0.26/8]	6.61 [0.60/30]
NF boards	6.52 [0.31/8]	5.27 [0.37/8]	6.89 [0.19/8]	5.48 [0.27/8]	6.04 [0.74/32]
NS boards	6.26 [0.32/9]	5.17 [0.44/8]	6.70 [0.34/8]	5.48 [0.42/8]	5.91 [0.71/33]
PF walls	6.81 [0.42/15]	5.87 [0.51/16]	7.14 [0.35/8]	5.70 [0.40/8]	—
PT walls	6.75 [0.46/8]	5.63 [0.58/7]	7.21 [0.39/16]	6.15 [0.45/8]	—
OF walls	6.40 [0.41/8]	5.36 [0.64/8]	6.39 [0.46/8]	5.68 [0.38/16]	—
All	6.69 [0.46/32]	5.69 [0.60/31]	7.12 [0.41/32]	5.80 [0.45/32]	6.33 [0.77/127]

[a]BF, back-primed, factory finished; BS, back-primed, site finished; NF, no back-priming, factory finished; NS, no back-priming, site finished; PF, plywood with felt; PT, plywood with polyolefin weather barrier; OF, felt, no sheathing.

varied between 5% and 8% MC, with an average of 6.3%. Siding MC of both buildings was essentially the same. These averages agree well with the hourly MC data collected by computer. The final average MC of the siding was 6% to 7% for both buildings.

To assess the influence of wall orientation and finishing type, we sorted the data by direction and finishing type. In most cases, this significantly reduced the standard deviation in the data. The results are tabulated in Table 6.

Effect of Wall Orientation

We determined if there was a statistically significant influence of wall orientation by applying the *t*-test to differences in average MCs in Table 6, with a confidence coefficient of 0.95. Table 7 shows the results for the effect of orientation.

The following conclusions can be drawn about the effect of wall orientation on siding MC at time of removal:

- The effect of wall orientation on final siding MC was pronounced and masked the effect of other parameters.
- On both buildings, boards facing southwest were drier than those facing northeast at time of removal.
- On the overhang building, and probably also on the guttered building, boards facing southeast were drier than those facing northeast at time of removal.
- On the overhang building, boards facing southwest were drier than those facing northwest at time of removal.

Effect of Finish Treatment Type

We determined the effect of the finish treatment type with the same statistical approach we used to determine the effect of wall orientation. The results are tabulated in Table 8. The effect of finish treatment type on average MC at the time of removal was not as strong as the effect of wall orientation. Boards without back-priming tended to be drier than back-primed boards, especially on the overhang building. Significantly, at the time of removal, back-primed boards were never drier than boards without back-priming facing in the same direction.

Effect of Wall Construction

The data in Table 6 suggest that siding over walls with felt and without sheathing (OF) was slightly drier at the time of removal than siding over the other two wall construction types, but statistical analysis revealed no significant differences in final MC of siding over the three types of wall construction.

Table 7—Effect of wall orientation on average MC of siding at time of removal (results of statistical comparison of differences between average MC by finish treatment type (0.95 confidence coefficient))[a]

	Comparison of final siding MC by wall orientation					
Finish treatment	SW<NW?	NW<NE?	SE<NW?	SW<NE?	SE<SW?	SE<NE?
Guttered building						
BF				yes		yes
BS	yes	yes	yes	yes		yes
NF	yes	yes	yes	yes		yes
NS		yes		yes		
All types				yes		yes
Overhang building						
BF	yes		yes	yes		yes
BS	yes	yes	yes	yes		yes
NF	yes		yes	yes		yes
NS	yes			yes		yes
All types				yes		Yes

[a]SW, southwest facing; NW, northwest facing; SE, southeast facing; NE, northeast facing; BS, back-primed and site finished; NS, no back-priming, site finished; BF, back-primed, factory finished; NF, no back-priming, factory finished.

Table 8—Effect of finish treatment type on average MC of siding at time of removal (results of statistical comparison of differences between average MC by wall orientation (0.95 confidence coefficient))[a]

	Comparison of final siding MC by finish treatment					
Wall orientation	BS<BF?	NF<BF?	NS<BF?	NF<BS?	NS<BS?	NS<NF?
Guttered building						
Northwest		yes	yes	yes		
Southwest						
Northeast			yes		yes	
Southeast						
All						
Overhang building						
Northwest			yes		yes	
Southwest		yes	yes	yes	yes	
Northeast		yes	yes	yes	yes	
Southeast						
All						

[a]BS, back-primed and site finished; NS, no back-priming, site finished; BF, back-primed, factory finished; NF, no back-priming, factory finished.

Moisture Content Gradient Within Boards

To determine if there was a vertical moisture gradient within the boards at the time of removal, we collected ten 101.6-mm- (4-in.-) wide specimens, cut three horizontal 25- by 102-mm (1 by 4 in.) slices from the drip edge up, and determined the MC of each slice gravimetrically. The average MC of these specimens was 6.6%, and there was no evidence of a vertical MC gradient within boards.

Moisture Content of Siding Below Windows

Seven siding specimens were cut from directly below windows, mostly below windows that showed signs of water leakage. The average MC of these specimens was 6.9%. One water-stained specimen taken from below window GSc registered 9% MC. The rest of the specimens were all 6% or 7% MC (including one water-stained specimen from below window GWa), with an average of 6.6%, which is similar to the MCs of other siding.

Final Moisture Content of Trim

Most of the wood trim had MCs between 9% and 12%, as indicated by moisture meter measurements taken in May 1997. One reading was greater than fiber saturation (window trim, wall GNc), and a few were more than 20%. These included the lower end of a doorjamb on wall GNb (23% MC), where decay had been observed, and doorjambs on walls GSb (25%) and OSb (22%). Other readings of 20% to 23% were near ends of window trim (GNc, GNd, ONd) and near one end of the gable end trim above wall ONa (20%). All observations of 20% MC or higher were on gable ends. Table 9 shows the distribution of all MC readings for each building.

The MC readings of the wood trim on the overhang building tended to be lower, with none more than 22% MC. The readings on the overhang building also showed less variation.

Since all trim MC readings of 20% or more were on gable ends and most were on window or door trim (including pine doorjambs), we sorted the moisture meter data for window and door trim (including pine doorjambs) by wall type (gable-end wall or eave wall). The data are shown in Table 10.

With the exception of one reading taken above the decayed region in a doorjamb, moisture meter readings on window and door trim were taken in identical locations on each building. Therefore, paired *t*-tests could be performed on the data summarized in Table 7 (pairing by individual location) to compare trim MCs between buildings. On gable-end walls, the difference in window and door trim MCs between buildings was highly significant (confidence coefficient of 0.995), with the overhang building having the lower MC readings. Even when readings of 20% MC or more were deleted from the data set, a statistically significant (confidence coefficient of 0.99) difference in gable-end trim MC between buildings remained. Thus, the roof overhang helped to keep window and door trim dry on gable-end walls. On eave walls, however, the difference between buildings was not significant even when we used a confidence coefficient criterion of only 0.9. This suggests that at the eaves, where there is roof runoff, rain gutters are as beneficial as roof overhangs, provided the gutters are functional.

Table 9—Distribution of moisture content (MC) readings on wood trim taken in May 1997.

MC (%)	Guttered building, number of readings (percentage of readings)	Overhang building, number of readings (percentage of readings)
µ30	1 (0.6)	0
25 [MC < 30	1 (0.6)	0
20 [MC < 25	3 (1.7)	3 (1.6)
15 [MC < 20	20 (11.6)	12 (6.6)
10 [MC < 15	122 (70.9)	150 (82.4)
<10	25 (14.5)	17 (9.3)
Total	172 (100)	182 (100)

Table 10—Average moisture content (MC) of window and door trim in May 1997 by building and wall type

	Average MC (%) [standard deviation (% MC)/number of specimens]	
Type of wall	Guttered building	Overhang building
Gable-end	12.84 [4.10/78]	11.63 [2.33/78]
Eave	11.95 [1.92/54]	11.67 [1.74/54]

Final Moisture Content of Plywood Sheathing

We took a total of 13 specimens of plywood sheathing from both houses and determined their MC gravimetrically. All measured between 7% and 9%, with an average of about 8.2% MC, higher than that of the siding (approximately 6.4% MC). This is best explained by the fact that at the same RH, the equilibrium moisture content (EMC) of plywood is higher than that of hardboard. The higher MC reflects the sheathing's higher EMC values at comparable RH levels. Final in-place MCs of all sheathing specimens were within 1.5% MC of their sorption EMC value at 50% RH (which was equal to indoor RH). As with siding specimens, sheathing specimens from walls facing southeast and southwest were drier than specimens from other walls.

Inspection of Walls ONa and OWd

We opened one stud bay each in wall sections ONa and OWd in the overhang building. We did this from the interior, cutting away the drywall with a drywall saw and removing the insulation. These were the two stud bays for which we collected detailed air pressure data (see Instrumentation and Data Acquisition). Wall ONa had felt building paper over plywood sheathing, and wall OWd had a polyolefin weather barrier over plywood sheathing. In wall ONa, a firestop had been installed just below ceiling level between the (balloon-frame) studs. The firestop had been caulked to the plywood sheathing.

We found no evidence of excessive air leakage or moisture in wall ONa. Moisture meter readings of the wood framing in wall ONa were between 8% and 9%. In wall OWd, we found a gap of approximately 6 mm (1/4 in.) between the top plate and the sheathing, and we could feel air movement through this gap. The top of the insulation had collected dirt, which was further evidence of significant air movement. Thus, there was direct air moving through the eave vents into the top of the wall, bypassing the weather barrier and

sheathing. Moisture meter readings of the wood framing were between 8.5% and 11%, with the highest readings near the top.

Results of Site Inspections

General Observations

A total of 10 quarterly visual inspections were performed. At the last inspection in May 1997, all boards appeared to be in excellent condition. During the May 1995 inspection, a total of 40 caulking failures were discovered on both buildings. All but three of these occurred next to air dams. It is plausible that the failures adjacent to air dams were due to shrinkage of the air dams, which were made from treated lumber and were fairly wet at installation. Because air dams are not part of typical construction, Masonite Corporation and FPL agreed that the failures next to air dams should be repaired, but that the other three failures should not be repaired. However, in our September 1995 inspection, we discovered that the contractor had repaired all caulking failures. The repairs of the three caulk failures not adjacent to air dams 6 months after installation would represent an exceptional level of maintenance by a homeowner. Subsequent caulk failures were not repaired.

During the September 1995 inspection, heavy mildew was noted on some of the caulking, especially on lower window trim joints. This mold remained present throughout the remainder of the test. One lower window caulk seam had failed. Summer 1995 was unusually wet in southern Florida, with rainfall about 580 mm (23 in.) above normal.

During the December 1995 inspection, mildew was noted on portions of 46 boards on the guttered building and on portions of 71 boards on the overhang building. The vast majority of these boards were factory-finished, suggesting that the paint used for site finishing had a more effective mildewcide. Most of the mildew was on the northwest and northeast sides of the buildings, the sides that receive the least amount of direct sunlight.

Iron staining of part of wall section B on the northwest side of the guttered building was present at the September 1995 inspection. This was caused by an irrigation sprinkler wetting the siding during August and September 1995. A guard dog had dug the sprinkler head out of the turf, which made it fall over and spray in the direction of the building. This was corrected on September 10, 1995. We suspect that wetting by the sprinkler occurred for roughly a month. The irrigation water hit one end of an instrumented board, and we have identified a 1-month period during which it appeared to have been periodically wetted by the sprinkler. At the September 1995 inspection, boards that were iron-stained were not thicker than adjacent boards that were not iron-stained.

The May 1997 inspection found the buildings and siding in essentially the same condition as in December 1995, when mildew was first noticed. In respects other than mildew, the siding was in virtually the same condition as in December 1994. Although the siding was obviously exposed to very high moisture and humidity conditions, all boards appeared to be in good condition. This observation is supported by the measurements.

Thickness Measurements

Thickness measurements on all boards were performed at the time of installation in December 1994 and at the nine subsequent quarterly inspections. Summaries of these data are shown in Figures 15 to 20.

Initial Board Thickness

The average initial thicknesses of site-finished boards (NS and BS) on the guttered building, as measured in December 1994, were 0.13 to 0.15 mm (0.005 to 0.006 in.) greater than those on the overhang building. Gutters were installed after siding installation, leaving the boards on that building more exposed to rain than the boards on the overhang building (gutters were installed in late December 1994 or January 1995). We therefore suspect that boards on the guttered building, especially boards that were left unpainted for a short period of time, may have been wetter at the time of first thickness measurement. This would explain the greater initial thickness of site-finished boards on the guttered building than on the other building. However, it is reasonable to assume that average board thickness was the same on both buildings at the time of installation.

We measured the thickness of 48 board samples, collected at the building site at the time of installation, after conditioning at 50% RH at FPL. The average thickness was about 10 mm (0.4 in.), but the standard deviation within each of the four board groups (grouped by finish treatment) was 0.08 to 0.15 mm (0.003 to 0.006 in.). This variation did not allow us to distinguish between the four finish treatments. Moreover, half the boards in this sample were site-finished but actually had been primed only and had not received their finish coating. Only boards actually installed on the building were site-finished after installation.

In the following analysis, we assume that the initial average thickness of boards is 10 mm (0.4 in.). This choice is conservative, because back-priming obviously added to the board's thickness and using this number to calculate thickness swell produces somewhat conservative estimates (that is, actual swelling may be slightly less than reported).

Thickness Swell

Figures 15 through 20 show that the increase in thickness of all boards was very small. Assuming initial board thickness of 10 mm (0.4 in.), average board thickness increased by about 0.20 mm (0.008 in.), or 2%, from December 1994 to May 1997. As mentioned earlier, this is a conservative

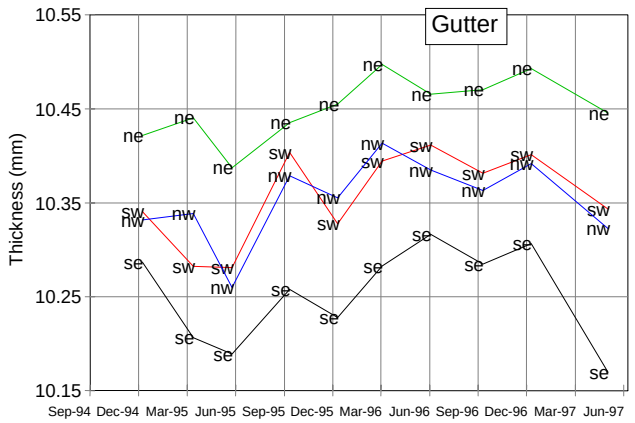

Figure 15—Results of thickness measurements on guttered building, by wall orientation (northeast, northwest, southeast, southwest).

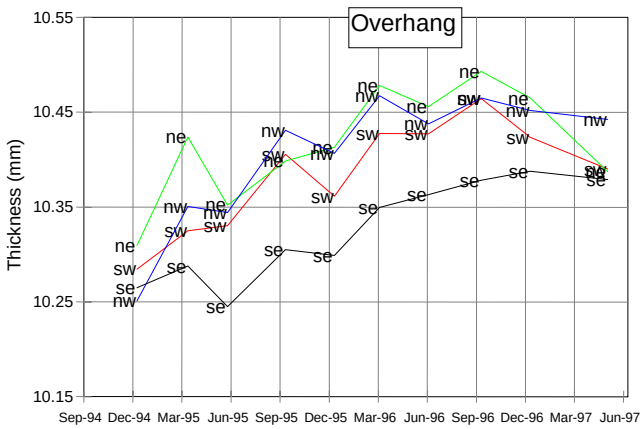

Figure 16—Results of thickness measurements on overhang building, by wall orientation (northeast, northwest, southeast, southwest).

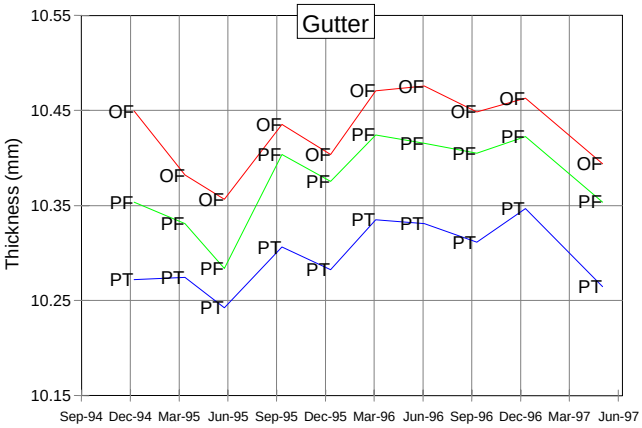

Figure 17—Results of thickness measurements on guttered building, by wall construction type (OF, no sheathing with felt; PF, plywood with felt; PT, plywood with polyolefin weather barrier).

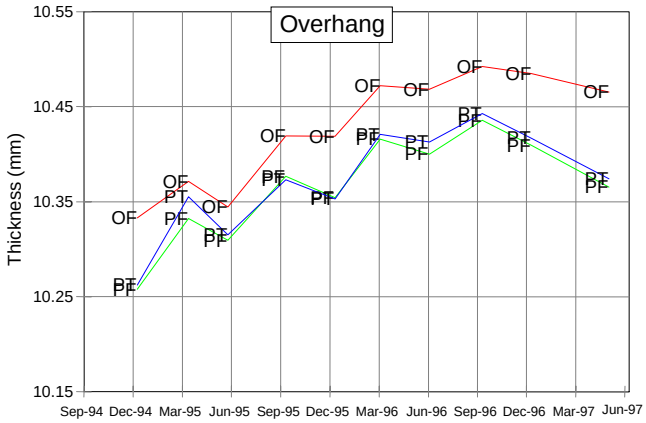

Figure 18—Results of thickness measurements on overhang building, by wall construction type (OF, no sheathing with felt; PF, plywood with felt; PT, plywood with polyolefin weather barrier).

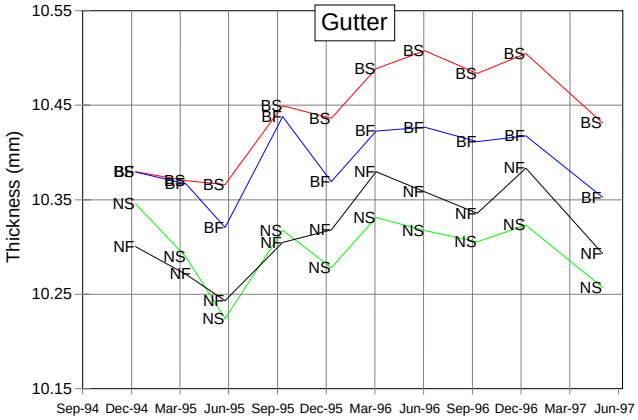

Figure 19—Results of thickness measurements on guttered building, by siding finish type (BS, back-primed, site finished; NS, not back-primed, site finished; BF, back-primed, factory finished; NF not back-primed, factory finished).

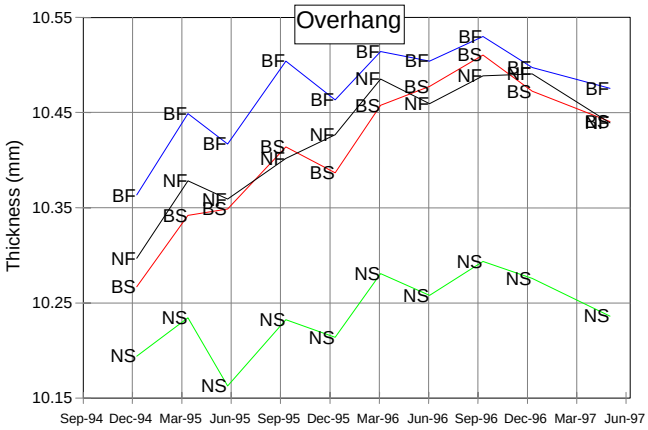

Figure 20—Results of thickness measurements on overhang building, by siding finish type (BS, back-primed, site finished; NS, not back-primed, site finished; BF, back-primed, factory finished; NF not back-primed, factory finished).

estimate and actual average thickness swell is probably somewhat lower. The data for the overhang building (Figs. 16, 18, and 20) suggest that, after some initial swelling immediately after installation, very little additional swelling took place. All figures show seasonal variations, but net increases after March 1995 were very small, 0.1 mm (0.004 in.) or less, and after June 1996, no long-term increase in thickness is apparent.

Effect of Orientation—The effect of orientation seemed consistent on both buildings (Figs. 15 and 16) during the first 2 years of exposure, with northeast-facing boards the thickest and southeast-facing boards the thinnest on both buildings.

However, on the overhang building, this trend did not continue and northwest-facing boards ended up with the most thickness swell, with the other orientations roughly equal. Thus, the thickness swell data do not show the effect of orientation as consistently and clearly as the final MC data taken from siding samples.

Effect of Wall Construction—Figures 17 and 18 suggest that on both buildings, siding on walls without sheathing (OF) measured slightly thicker than boards on other wall types throughout the measurement period. Assuming an initial average thickness of 10 mm (0.4 in.) at installation, the average thickness swell of boards installed on walls without sheathing (OF) on the guttered building was about 0.23 mm (0.009 in.), or 2%, at the time of dismantling in May 1997 and 0.30 mm (0.012 in.), or 3%, on the overhang building. The corresponding average thickness swell of boards installed over plywood and felt (PF) was about 0.20 mm (0.008 in.), or 2%, on both buildings. The final thickness swell of boards over the polyolefin weather barrier (PT) on the guttered building was only 0.10 mm (0.004 in.), or 1%, and about 0.20 mm (0.008 in.), or 2%, on the overhang building.

Effect of Back-priming and Site Finishing—We used the same initial thickness for the analysis of effects of finishing treatment, although we realized that the site and factory paint coatings are probably not exactly equal in thickness. The finish treatments are as follows: site-finished without back-priming (NS), site-finished with back-priming (BS), factory-finished without back-priming (NF), and factory-finished with back-priming (BF). Figures 19 and 20 show few consistent differences in thickness swell by treatment type, except that on both buildings, boards that were site-finished without back-priming (NS) seemed to swell the least. On the guttered building, factory-finished boards without back-priming (NF) swelled somewhat less than back-primed boards (BS and BF), but this is not confirmed by the data for the overhang building. In addition, part of these differences can be ascribed to differences in initial thickness. Nevertheless, the data do indicate that back-priming did not decrease thickness swell.

Effect of Gutters and Overhangs—The thickness measurements do not reveal significant differences between the two buildings in board thickness swell.

Results of Automated Data Collection

Outdoor Humidity and Temperature

Data from the two weather stations show that daily maximum summer temperatures generally were between 65°C (85°F) and 76°C (105°F), and maximum RH was between 75% and 95%. During winter, maximum daily values dropped to between 54°C (65°F) and 68°C (90°F) with RH between 50% and 90%.

Rainfall

A summary of rain data collected on-site, as well as data from the nearest National Weather Service (NWS) station at West Palm Beach, Florida, about 26 km (16 mi) from the test site, are shown in Table 11. The NWS data and the site-collected data are in general agreement. Using site-collected data for the period April 28, 1995, through May 5, 1997, (approximately 2 years of data) and normalizing for the number of days in this period gives annual rainfall of approximately 1,500 mm (59 in.) per year at the site. This is close to the historical average (years 1961–1990) of 1,550 mm (61 in.) per year at the NWS site in West Palm Beach.

Using NWS data, we calculated the climatic decay hazard index (Scheffer 1971) during the period that the siding was exposed. We used NWS data because calculation of decay hazard index requires daily rain data. Site-collected data did not contain this information, since it was collected on weekly intervals. The index value was developed as an indicator of the potential for decay of wood exposed on building exteriors above ground. The calculated value for the exposure

Table 11—Summary of rainfall data (December 4, 1994 to May 9, 1997)

	Cumulative rainfall (mm (in.))	
Period	NWS[a] data	Site data
Dec. 12, 1994 to Apr. 14, 1995	287 (11.3)	Not collected
Apr. 14, 1995 to Dec. 29, 1995	1,293 (50.9)	1,494 (58.8)
Dec. 29, 1995 to July 5, 1996	518 (20.4)	582 (22.9)
July 5, 1996 to Jan. 3, 1997	511 (20.1)	494 (19.4)
Jan. 3, 1997 to May 9, 1997	450 (17.7)	475 (18.7)

[a]NWS, National Weather Service.

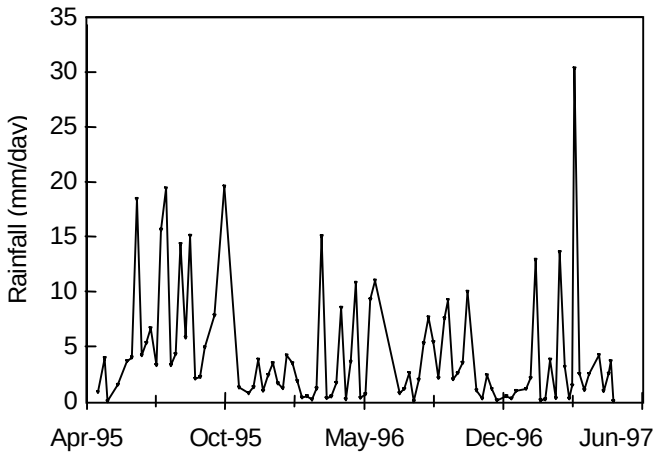

Figure 21—Average daily rainfall for April 1995 through May 1997.

period was 154. This is an exceptionally high value, indicating that climatic conditions during the exposure period were very conducive to decay of wood products on building exteriors. Index values in excess of 65 (based on historic average data) indicate climates of high decay hazard. Index values for the continental United States (based on historic average data) exceed 110 only for the Florida peninsula (Scheffer 1971).

Figure 21 shows the average daily rainfall, calculated from the rain gauge data, from April 1995 through May 1997. It shows that the summer of 1995 was especially wet.

Wind Speed and Direction

As mentioned previously, hourly wind speed and direction data were collected starting in the middle of September 1995. Figure 22 shows the daily maximum and average wind with the dominant direction for November 11 through December 8, 1995. The data generally agreed with patterns of air pressure differences across the siding (that is, positive pressure differences on the windward side, negative on all other sides), increasing our confidence in the accuracy of pressure and wind data.

Air Pressure

Air Pressures Across Siding

Figures 23 to 30 show maximum, minimum, and average air pressure difference across the siding on the eight locations on the guttered building for each hour between November 11 and December 8, 1995, the same time period as in Figure 22. This period was chosen as representative of the entire data set. Positive pressure means that the air pressure exterior to the siding exceeds the air pressure in the airspace between the siding and the building paper (or polyolefin air barrier), and a negative pressure means air pressure behind the siding exceeds air pressure exterior to the siding. Designations on the plots (GNa, GNd, GEa, GEd, ONa, etc.) are the designations given to wall sections (Fig. 4). Because the buildings were oriented 180 degrees from the planned orientation, wall sections Na through Nd actually faced southwest.

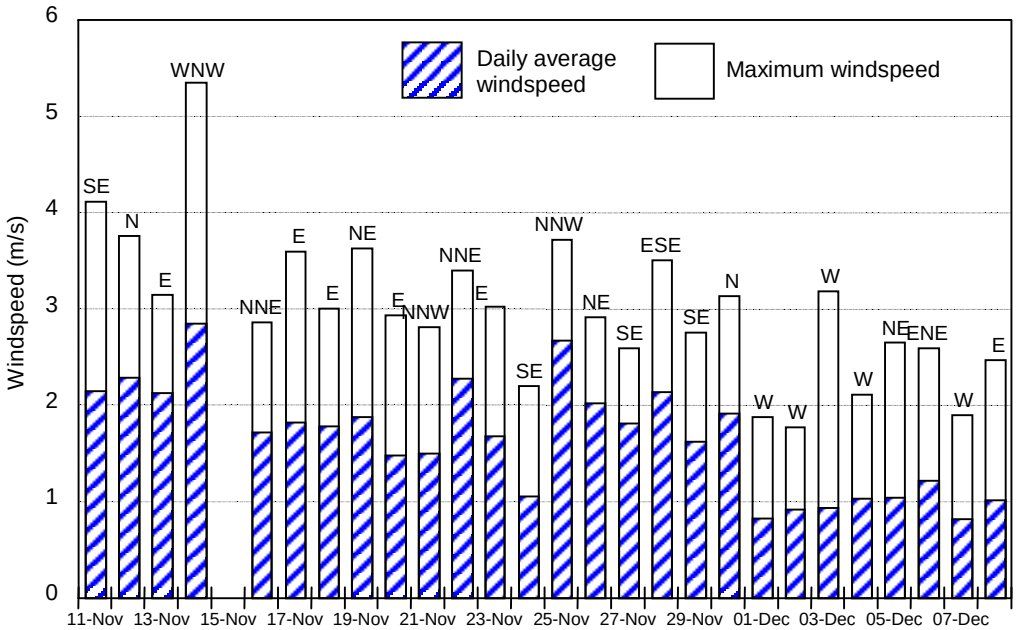

Figure 22—Average and maximum daily wind speed and dominant wind direction for November 11 through December 8, 1995.

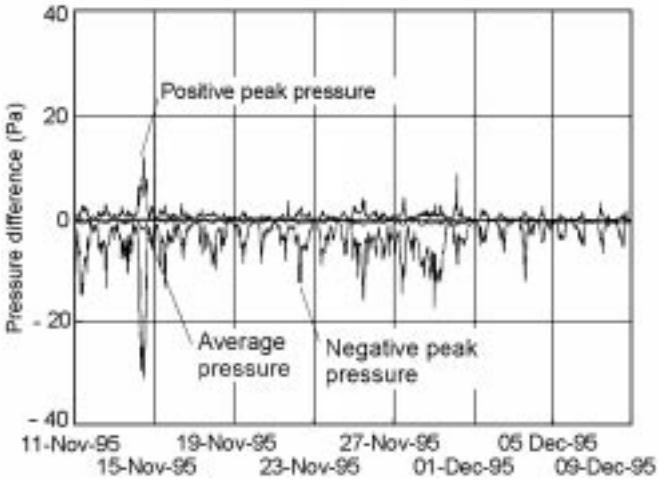

Figure 23—Average, maximum, and minimum air pressure difference across siding on wall section GNa (southwest-facing) of guttered building, November 11 through December 8, 1995 (positive values indicate that exterior air pressure exceeded air pressure on back of siding).

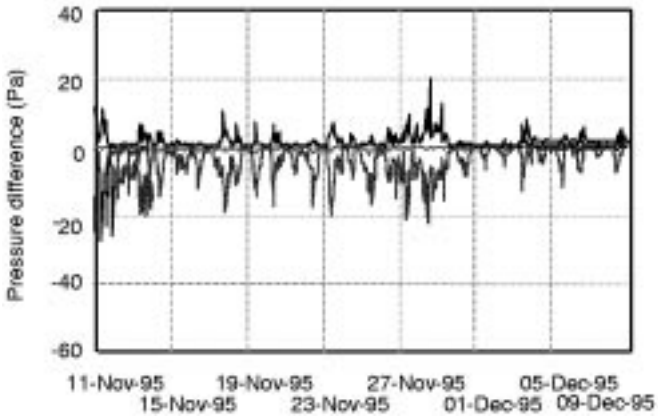

Figure 25—Average, maximum, and minimum air pressure difference across siding on wall section GWa (southeast-facing) of guttered building, November 11 through December 8, 1995 (positive values indicate that exterior air pressure exceeded air pressure on back of siding).

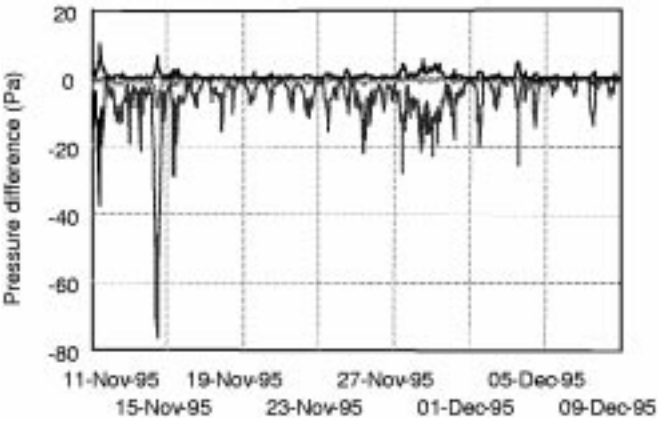

Figure 24—Average, maximum, and minimum air pressure difference across siding on wall section GNd (southwest-facing) of guttered building, November 11 through December 8, 1995 (positive values indicate that exterior air pressure exceeded air pressure on back of siding).

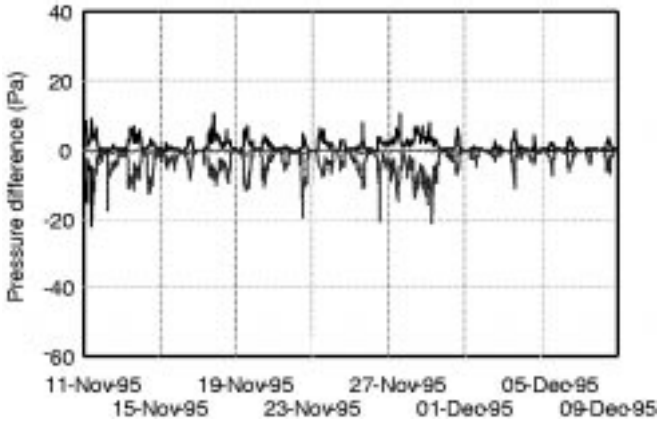

Figure 26—Average, maximum, and minimum air pressure difference across siding on wall section GWd (southeast-facing) of guttered building, November 11 through December 8, 1995 (positive values indicate that exterior air pressure exceeded air pressure on back of siding).

Figures 23 to 30 reflect the gusty and turbulent nature of wind pressure, as well as changes in wind direction. During all hours, both positive and negative air pressure differences occurred across the siding on all sides of the building. As the figures show, peak pressure differences of 20 Pa are common on windy days. During the afternoon of November 14, 1995, extreme negative pressures of –40 to –60 Pa or lower were recorded in some locations. This was a particularly windy day with WNW winds. With WNW winds, pressures would be expected to be positive on wind-facing walls (northwest) and primarily negative on the other walls.

On November 14, pressures on northwest-facing walls GEa (Fig. 29) and GEd (Fig. 30) had the highest positive values, while southwest- and northeast-facing walls parallel to the wind direction (GNa, GNd, GSc, and GSd) registered the most extreme negative pressures.

Maximum negative pressures usually exceeded maximum positive pressures and the average pressure (average of slightly more than 600 individual 5-s readings per hour) was generally slightly negative on most sides of the building. Both buildings produced very similar air pressure data. This slight pressurization of the back of the siding was most prominent when the wind was strong. We have not found a convincing explanation for this phenomenon.

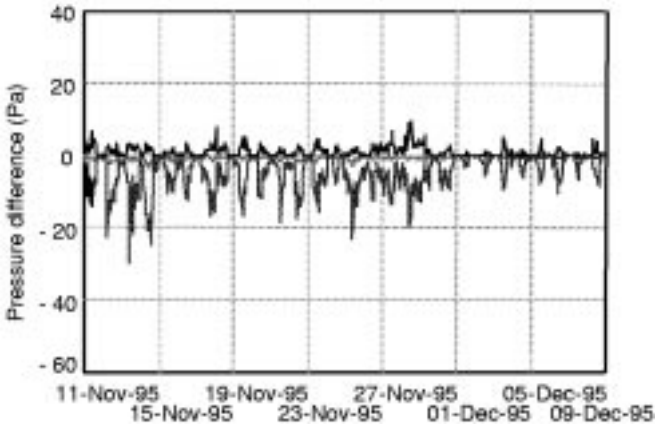

Figure 27—Average, maximum, and minimum air pressure difference across siding on wall section GSa (northeast-facing) of guttered building, November 11 through December 8, 1995 (positive values indicate that exterior air pressure exceeded air pressure on back of siding).

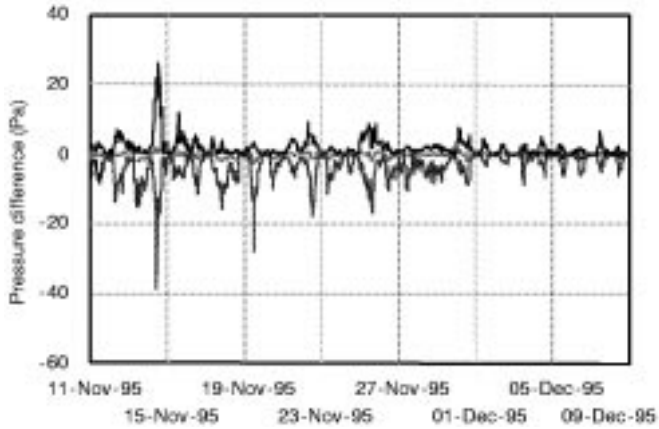

Figure 29—Average, maximum, and minimum air pressure difference across siding on wall section GEa (northwest-facing) of guttered building, November 11 through December 8, 1995 (positive values indicate that exterior air pressure exceeded air pressure on back of siding).

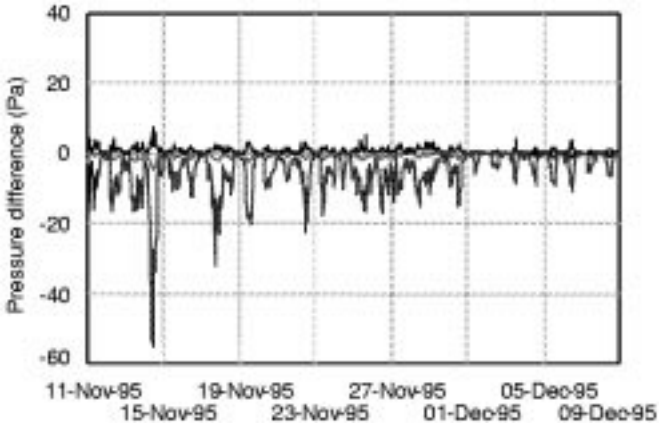

Figure 28—Average, maximum, and minimum air pressure difference across siding on wall section GSc (northeast-facing) of guttered building, November 11 through December 8, 1995 (positive values indicate that exterior air pressure exceeded air pressure on back of siding).

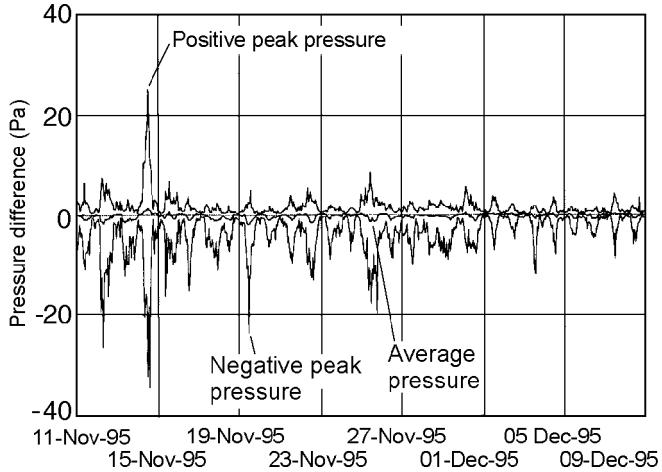

Figure 30—Average, maximum, and minimum air pressure difference across siding on wall section GEd (northwest-facing) of guttered building, November 11 through through December 8, 1995 (positive values indicate that exterior air pressure exceeded air pressure on back of siding).

It has been argued in recent years that, to properly function as a rain screen, wood-based siding should be spaced out from the sheathing and ventilated to provide air pressure equalization. The pressure data suggest that conventionally installed lap siding provides some air pressure equalization, although relatively large exfiltrative pressure peaks occasionally occur. These exfiltrative pressures do not cause concern for water penetration, and therefore, an air space does not appear necessary for that purpose. (When we dismantled the building in May 1997, we removed and inspected most of the siding. There was no evidence of water staining on the back of the siding or on the building paper other than some evidence of leakage that had occurred due to caulk failures around windows.) An air space may still be beneficial but primarily because it provides better drainage of water that may penetrate to the back of the siding (especially around windows and doors). An air space would reduce the chance of this water penetrating the weather barrier and wetting the sheathing.

Air Pressures in Walls ONa and OWd

On October 8, 1996, pressure taps were rearranged as described in Table 5. This allowed a more detailed look at the pressure differences across wall sections OWd and ONa, specifically pressure differences across the sheathing–siding combination, across the entire wall, and across the siding.

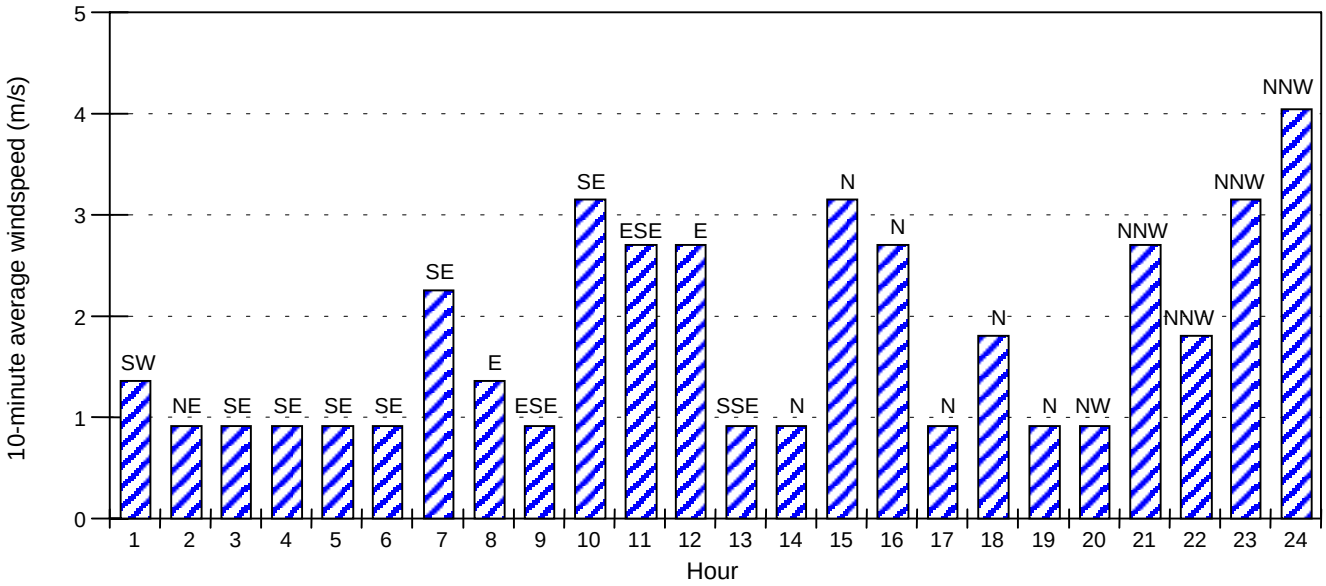

Figure 31—Hourly windspeed (10-min average) and direction on Oct. 18, 1996.

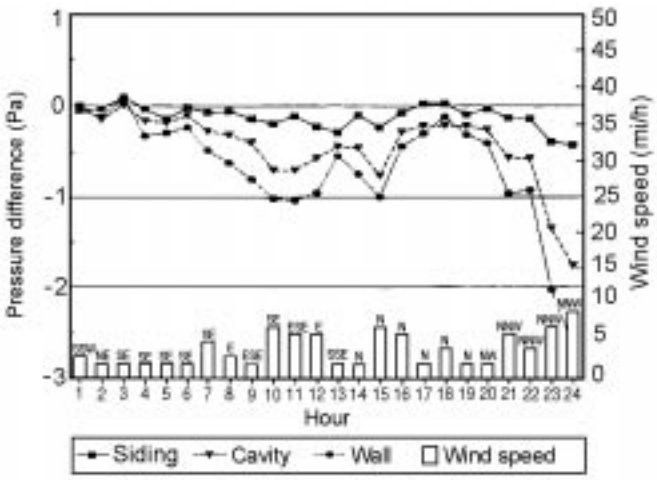

Figure 32—Hourly average pressure difference across siding, between the outside and the cavity, and across the entire wall for wall ONa on October 18, 1996 (positive values indicate that air pressure was infiltrative).

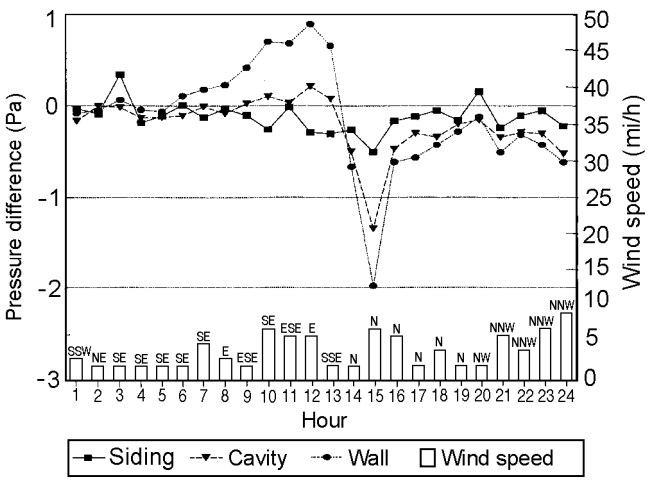

Figure 33—Hourly average pressure difference across siding, between the outside and the cavity, and across the entire wall for wall OWd on October 18, 1996 (positive values indicate that air pressure was infiltrative).

To demonstrate the pressure behavior of these walls, we focus on data collected on October 18, 1996, a day with typical windspeeds, and November 15, 1996, a very windy day.

Figure 31 shows the wind speed (10-min average) and predominant wind direction on October 18, 1996. This day was of interest because of the rapidly changing wind direction in the early afternoon. Figures 32 and 33 show the hourly average pressure difference across the siding, between the outside and the cavity, and across the entire wall for walls ONa and OWd, respectively. Wall section ONa (Fig. 32) was located on the west corner and faced southwest. The wall experienced exfiltrative (negative) pressures all day, even with south-southeast winds. Wall OWd (Fig. 33) was located on the east corner and faced southeast. It experienced infiltrative (positive) pressures with east to southeast winds, which abruptly changed to exfiltrative (negative) pressure when the wind shifted to the north. This illustrates that only wall sections near the windward corner experienced infiltrative pressures, while all other wall sections were under exfiltrative pressure. Average pressures across the siding were small (0.5 Pa or less) and relatively insensitive to wind speed. Hourly average pressures across the sheathing–weather barrier–siding combination were in the order of 0 to 0.5 Pa in both walls most of the time but increased to almost

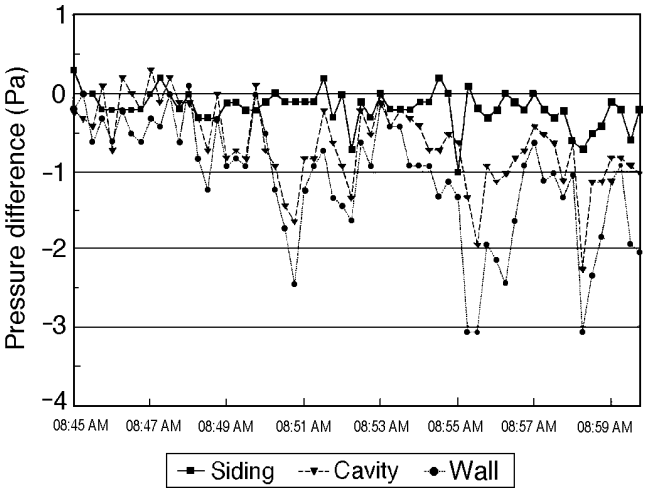

Figure 34—Instantaneous pressure difference across siding, between the outside and the cavity, and across entire wall for wall ONa between 8:45 and 9:00 a.m. on Oct. 18, 1996 (winds were from the southeast; positive values indicate that the air pressure was infiltrative).

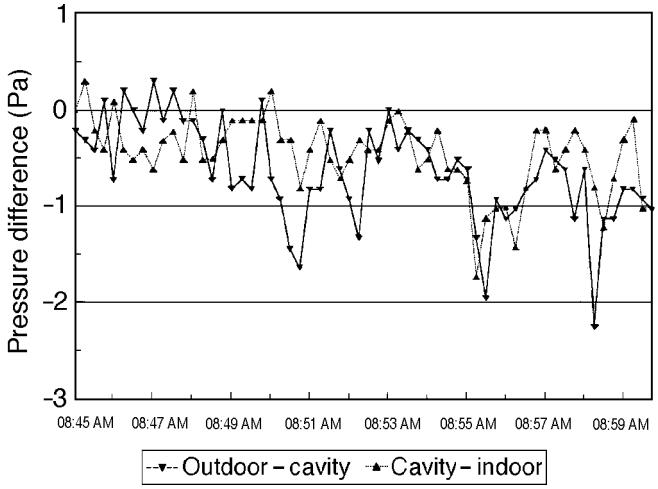

Figure 36—Instantaneous pressure difference between cavity of wall ONa and outside and inside air, respectively, between 8:45 and 9:00 a.m. on October 18, 1996 (winds were from the southeast; positive values indicate that the air pressure was infiltrative).

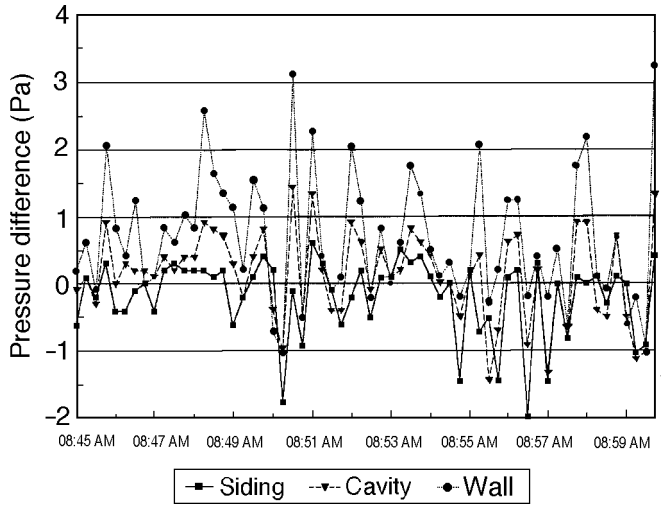

Figure 35—Instantaneous pressure difference across siding, between the outside and the cavity, and across entire wall for wall OWd between 8:45 and 9:00 a.m. on Oct. 18, 1996 (winds were from the southeast; positive values indicate that the air pressure was infiltrative).

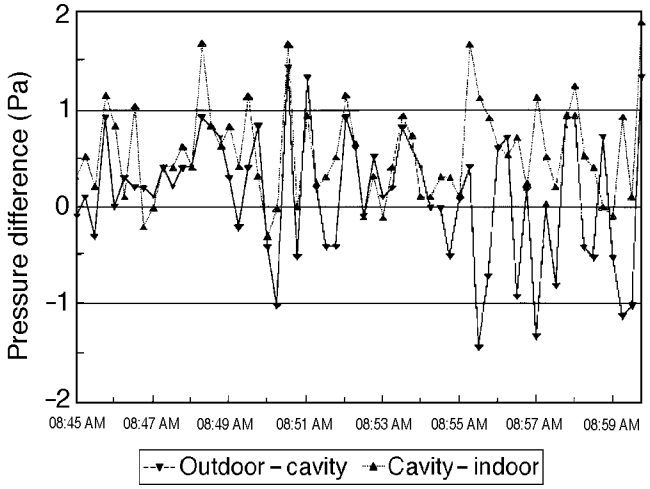

Figure 37—Instantaneous pressure difference between cavity of wall ONa and outside and inside air, respectively, between 12:15 and 12:30 p.m. on October 18, 1996 (winds were from the south-southeast; positive values indicate that the air pressure was infiltrative).

2 Pa in wall ONa near midnight (Fig. 32). Hourly average pressures across the gypsum board ($\Delta p_{\text{cavity}} - \Delta p_{\text{whole wall}}$) were about 0.5 Pa most of the time but approached 1 Pa in OWd during the middle of the day.

Figures 34 and 35 show instantaneous pressures between 8:45 and 9:00 a.m. on October 18, 1996. Winds were from the east to southeast at 0.9 to 1.3 m/s (2 to 3 mi/h) (10-min average). Data are shown as 15-s averages. Pressures across the siding on wall ONa (Fig. 34) remained well below 1 Pa, while exfiltrative pressures across the wall at times reached 3 Pa. Pressures on the windward wall OWd (Fig. 35) were of the same magnitude but fluctuated between infiltrative (positive) and exfiltrative (negative). This demonstrates that even a windward-facing wall can experience significant periods of exfiltrative airflows. The data also suggest that hourly average pressure data can be quite misleading when infiltrative and exfiltrative flows cancel each other in the averaging process. Figures 36 and 37 show the difference between pressure in the cavity and outside and inside pressure.

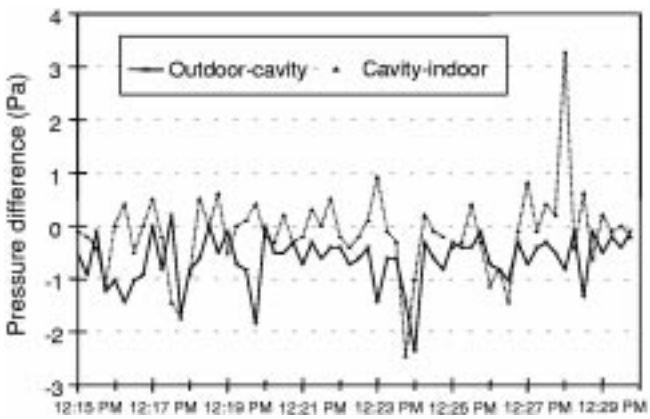

Figure 38—Instantaneous pressure difference between cavity of wall OWd and outside and inside air, respectively, between 8:45 and 9:00 a.m. on October 18, 1996 (winds were from the southeast; positive values indicate that the air pressure was infiltrative).

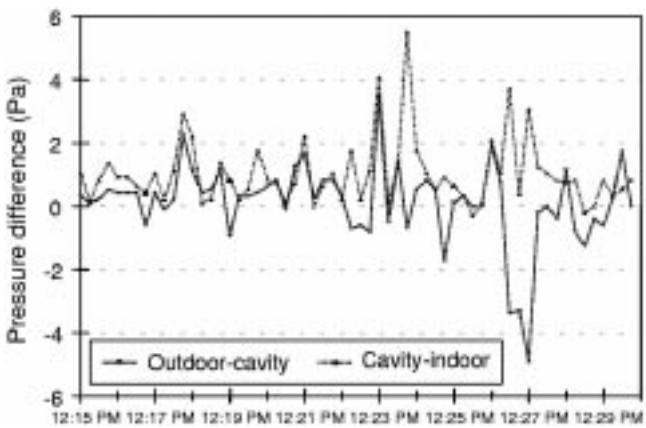

Figure 39—Instantaneous pressure difference between cavity of wall OWd and outside and inside air, respectively, between 12:15 and 12:30 p.m. on October 18, 1996 (winds were from the south-southeast; positive values indicate that the air pressure was infiltrative).

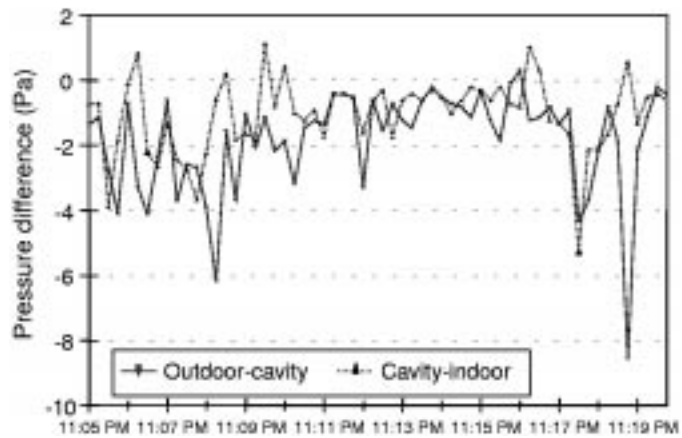

Figure 40—Instantaneous pressure difference between cavity of wall ONa and outside and inside air, respectively, between 11:05 and 11:20 p.m. on October 18, 1996 (winds were from the north-northeast; positive values indicate that the air pressure was infiltrative).

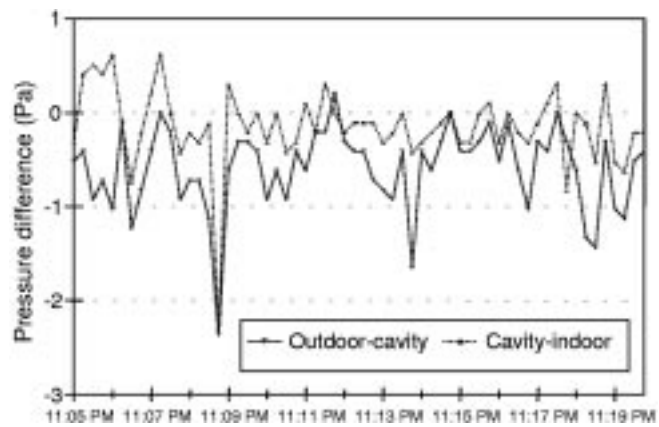

Figure 41—Instantaneous pressure difference between cavity of wall OWd and outside and inside air, respectively, between 11:05 and 11:20 p.m. on October 18, 1996 (winds were from the north-northeast; positive values indicate that the air pressure was infiltrative).

It appears that in both walls, pressure drops across the sheathing and siding were often similar in magnitude to pressure drops across the gypsum board, even though the sheathing with the weather barrier had been expected to resist most of the pressure. The large gap at the top plate that was revealed during inspection of wall section OWd explains the results for that wall, but in wall ONa, air apparently also bypassed the exterior sheathing and barrier to a considerable degree. Windward wall OWd also shows periods when the cavity appears simultaneously pressurized compared with inside and outside. We first observed and reported a similar phenomenon in walls with vents to the outside in a test building in Madison (TenWolde and others 1995). The current data indicate that the same effect takes place in conventional wood-framed walls. Figure 38 shows that 3½ h later, with slightly more southerly winds, the cavity of wall ONa also was pressurized for short periods of time. The cavity of wall OWd continued to be pressurized at times as well (Fig. 39). This pressurization was probably due to air infiltrating through the top of the wall. Finally, with winds from the north at 11:00 p.m., both walls were on the leeward side of the building and under exfiltrative pressure (Figs. 40 and 41). Pressurization of the cavity of either wall rarely occurred during that period.

Figures 42 and 43 present similar pressure data for November 15. Around 11:00 p.m., winds were strong from the east to northeast with windspeeds of around 8.1 m/s (18 mi/h) (10-min average). Pressure across the siding was still relatively modest, usually less than 2 Pa, with some spikes of 10 to 15 Pa. Some pressure spikes of 15 to 20 Pa occurred across the gypsum board, especially in wall ONa.

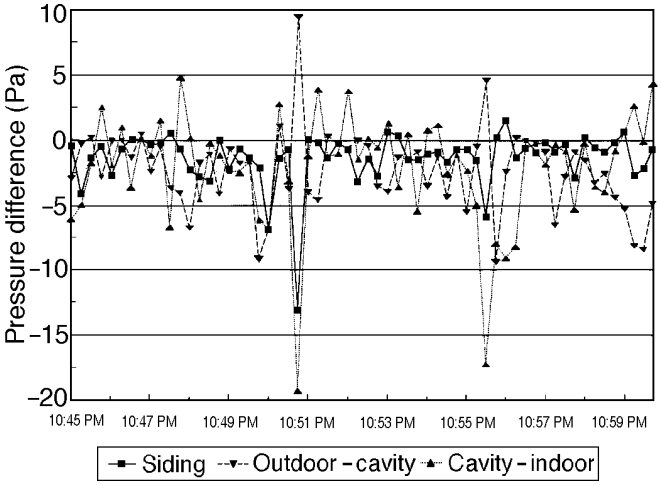

Figure 42—Instantaneous pressure difference across siding, between the outside and the cavity, and across entire wall for wall ONa between 10:45 and 11:00 p.m. on Nov. 15, 1996 (winds were from the north to northeast; positive values indicate that the air pressure was infiltrative).

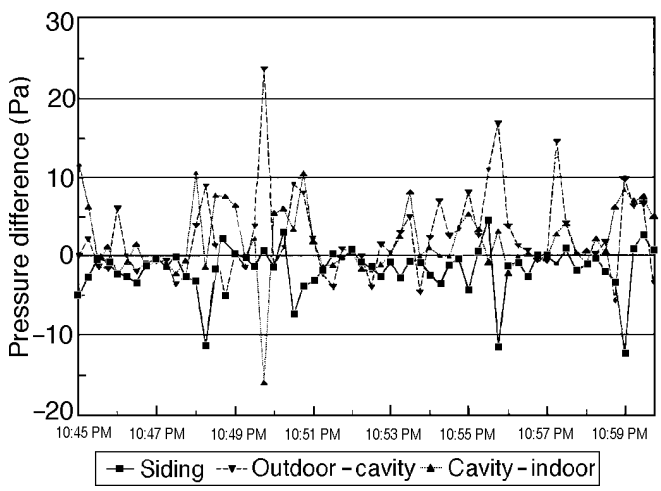

Figure 43—Instantaneous pressure difference across siding, between the outside and the cavity, and across entire wall for wall OWd between 10:45 and 11:00 p.m. on Nov. 15, 1996 (winds were from the east to northeast; positive values indicate that the air pressure was infiltrative).

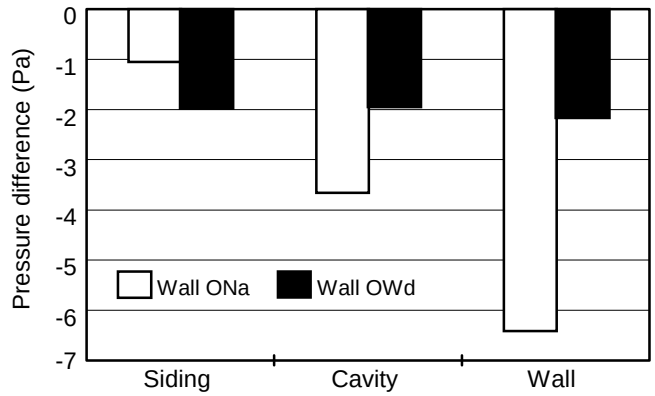

Figure 44—Fifteen-minute average pressure difference across siding, between the outside and the cavity, and across entire wall for walls ONa and OWd between 10:45 and 11:00 p.m. on Nov. 15, 1996 (winds were from the east to northeast; positive values indicate that the air pressure was infiltrative).

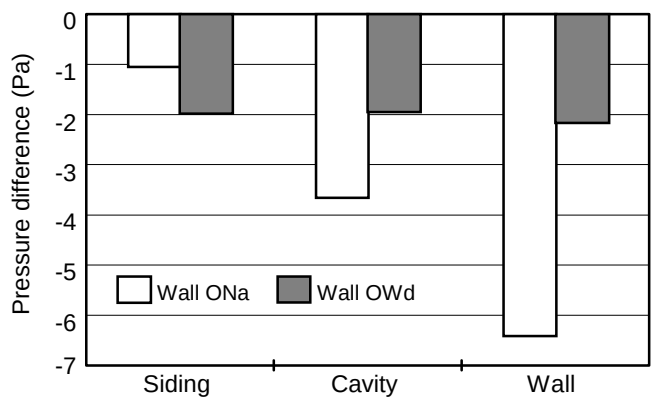

Figure 45—Ten-minute average pressure difference across siding, between the outside and the cavity, and across entire wall for walls ONa and OWd between 10:05 and 10:15 p.m. on Nov. 15, 1996 (winds were probably from the east to northeast; positive values indicate that the air pressure was infiltrative).

Figure 44 shows pressures averaged across the same 15-min period. It shows that wall ONa had an average exfiltrative pressure of about 6 Pa, and the sheathing–weather barrier–siding combination exhibited a pressure of almost 4 Pa. This means that the gypsum board sustained an average pressure of about 2 Pa. The siding pressure difference was slightly greater than 1 Pa. The average pressure across wall OWd was in the inward direction but was only about 2 Pa, primarily because there were many pressure reversals (OWd was on the windward corner of the building). Pressure across the gypsum board was about 2 Pa (inward direction). Finally, Figure 45 shows averages for data taken 45 min earlier. These average pressures for the downwind wall (ONa) were very similar, but the pressures across wall OWd are reversed in direction, indicating a slightly different (probably more northerly) wind direction during that period.

Several observations can be made from all the data presented:

- There was reasonably good pressure equalization across the lap siding.
- Pressures across the gypsum board were greater than expected, probably because of air leakage through the top of the wall.
- Most of the walls experienced exfiltrative wind pressures most of the time; only walls on the windward corner experienced extensive periods of inward pressure, but even then, many pressure reversals occurred.
- Windward walls sometimes experienced short periods of pressurization of the cavity, with pressures that were higher than outside and inside pressures. This most likely occurred because of air infiltrating through the top of the wall.

The data as well as the inspection of the walls indicate that exterior air barriers have limited value if the top plate is not carefully sealed.

Moisture Content

Data Reliability

In-place MCs of the siding on the test building during exposure were indirectly measured by electric resistance in the board between two pins. The pin readings were calibrated at FPL for the specific siding used in this study. The electric resistance became too large to measure when boards dropped below 7% MC, and therefore, 7% was the lowest measurable MC. Because of the resolution of our data acquisition system and the noise in the system, our resolution was 10 mV, which translates into an uncertainty of about ±2% MC between 7% and 10.5% MC. Uncertainty in temperature correction factors provided an additional error, which we estimate at 1% to 2% MC. We therefore believe that in the MC range of 7% to 10.5%, the total error of individual MC measurements was in the range of 3% to 4% MC. Above 10.5%, errors decreased and resolution improved. However, averaging the results from many sensors improved accuracy, even in the low MC range. Indeed, a comparison of final gravimetrically obtained MCs with hourly MC pin data suggested that the error in average MCs was about 1% MC.

Moreover, when differences between MCs were considered, much of the error in the temperature correction tended to be canceled out (that is, the error in both MCs was probably of the same magnitude and direction). Therefore, when considering differences between MC levels, we ignored the temperature correction error.

An additional error in hourly MC readings occurred during periods of rain. Apparently, with the dry siding providing high electrical resistance, liquid water on the pins provided a sufficient shunt resistance to cause spikes of higher readings. These spikes are evident in Figures 46 to 58. However, MC readings would quickly return to their previous values afterwards.

During a site visit in early February 1996, we repaired and cleaned a number of MC pins. We also found defective amplifier circuits for five MC pins on the guttered building. We rerouted two pin pairs to unused amplifiers and disconnected defective circuits. During this visit, computer thermocouple boards were also recalibrated. The MC data in Figure 46 show that these repairs and recalibrations had a profound influence on the MC readings. After resumption of data collection on February 9, 1996, the average of all MC readings dropped to about 6% to 7% on both buildings, which is the lowest measurement limit of the MC pins. These readings were verified with several measurements from a hand-held electric resistance moisture meter, which indicated MCs between 6% and 7.5%. The defective amplifier circuits that were repaired or disconnected during the February visit apparently had an undue influence on the MC results for the guttered building prior to the visit. Recalibration of temperature circuits is responsible for the much smaller decrease in MC readings on the overhang building.

Differences Between Buildings

There was no significant difference between measured average MCs of the two buildings after the repairs of the MC pins in February 1996 (Fig. 46).

Effect of Back-Priming and Finishing

Figures 47 to 50 show no discernable effect of finishing treatments on the MC readings after February 15, 1996. All boards were essentially dry.

Effect of Wall Construction

Figures 51 to 53 show no discernable effect of the type of wall construction (open with felt, plywood with felt, or plywood with polyolefin weather barrier) on the MC readings after February 15, 1996. All boards were essentially dry.

Effect of Orientation

Figures 54 to 57 show no discernable effect of wall orientation on the MC readings after February 15, 1996. All boards were essentially dry.

Bottom Boards

After February 15, 1996, the data show no discernable difference in MC between bottom boards and boards in other locations (Fig. 58).

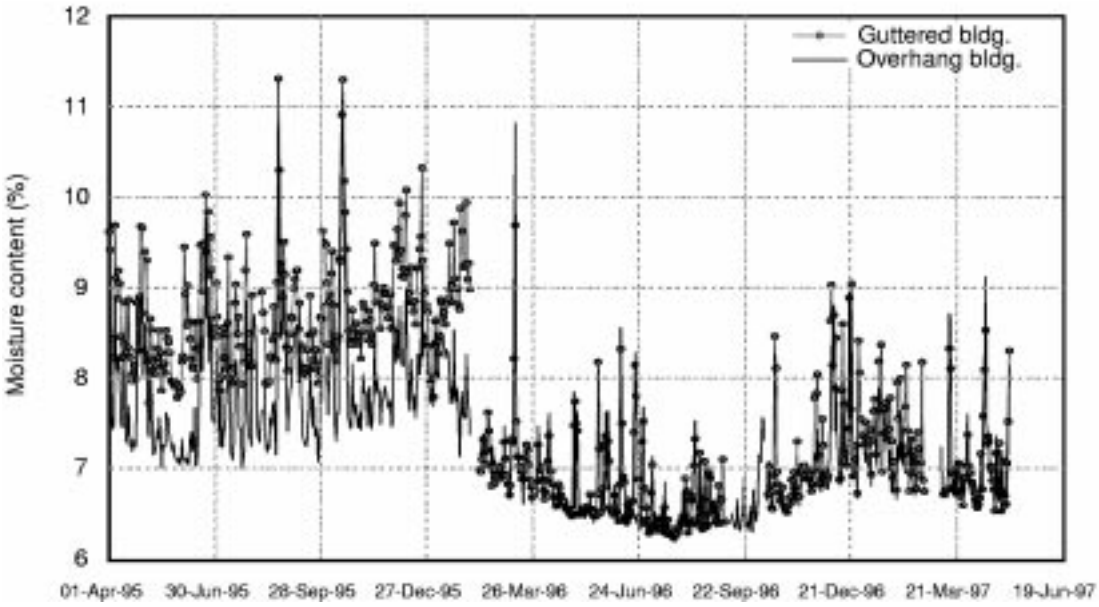

Figure 46—Daily average moisture content of all siding on both buildings for April 1, 1995, through May 5, 1997.

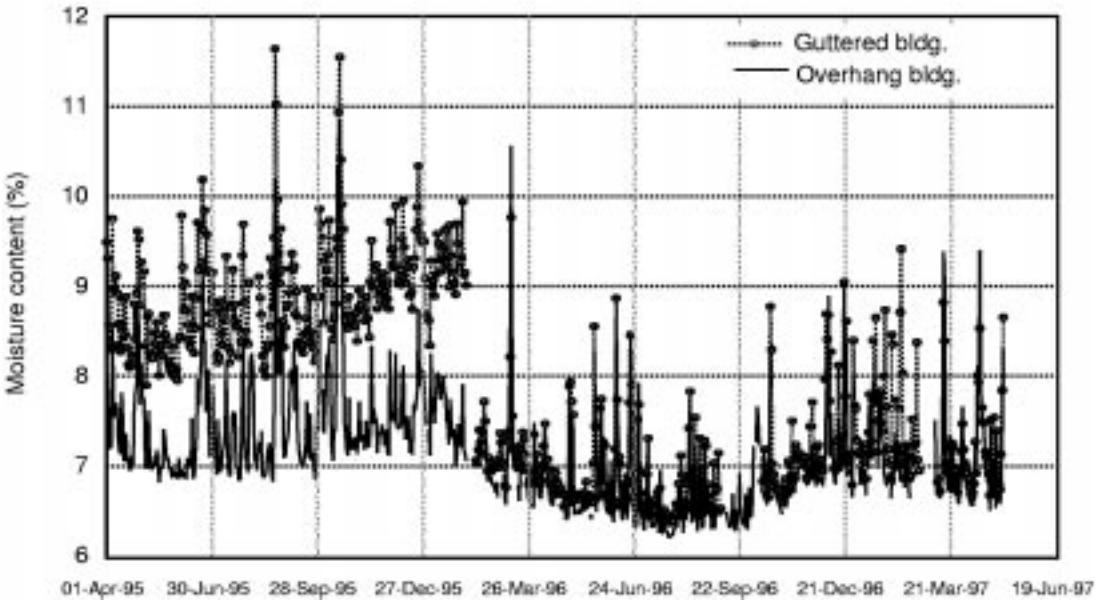

Figure 47—Daily average moisture content of back-primed, site-finished (BS) siding on both buildings for April 1, 1995, through May 5, 1997.

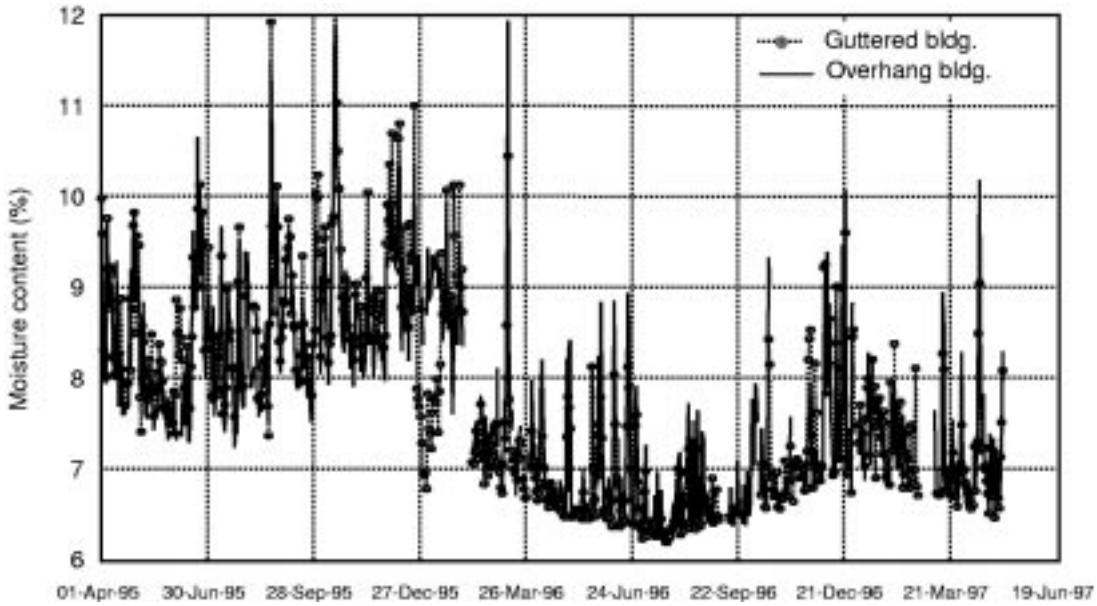

Figure 48—Daily average moisture content of back-primed, factory-finished (BF) siding on both buildings for April 1, 1995, through May 5, 1997.

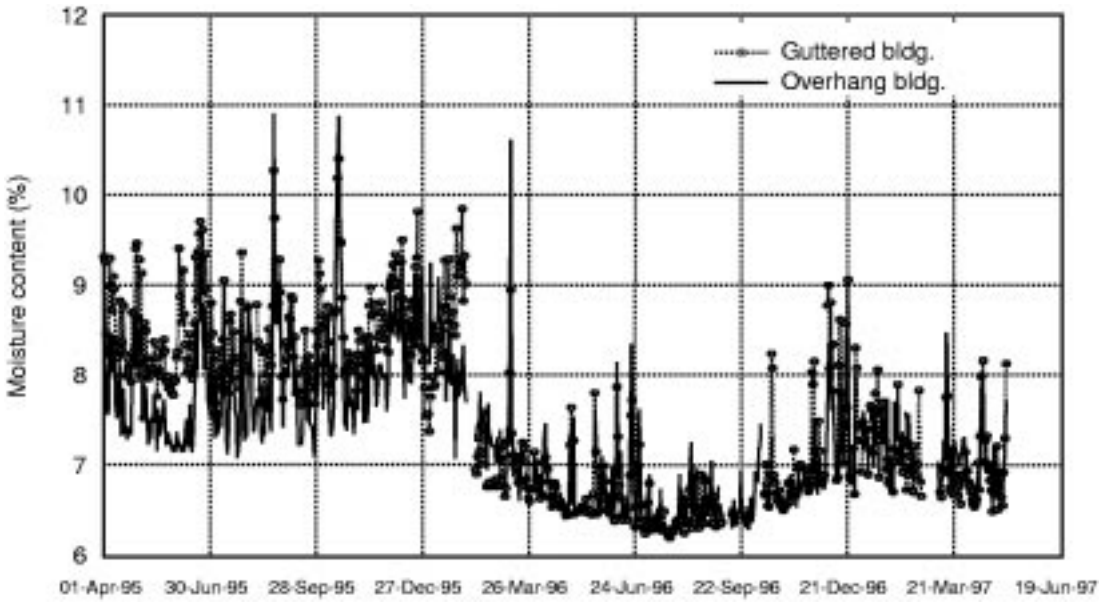

Figure 49—Daily average moisture content of site-finished siding without back-priming (NS) on both buildings for April 1, 1995, through May 5, 1997.

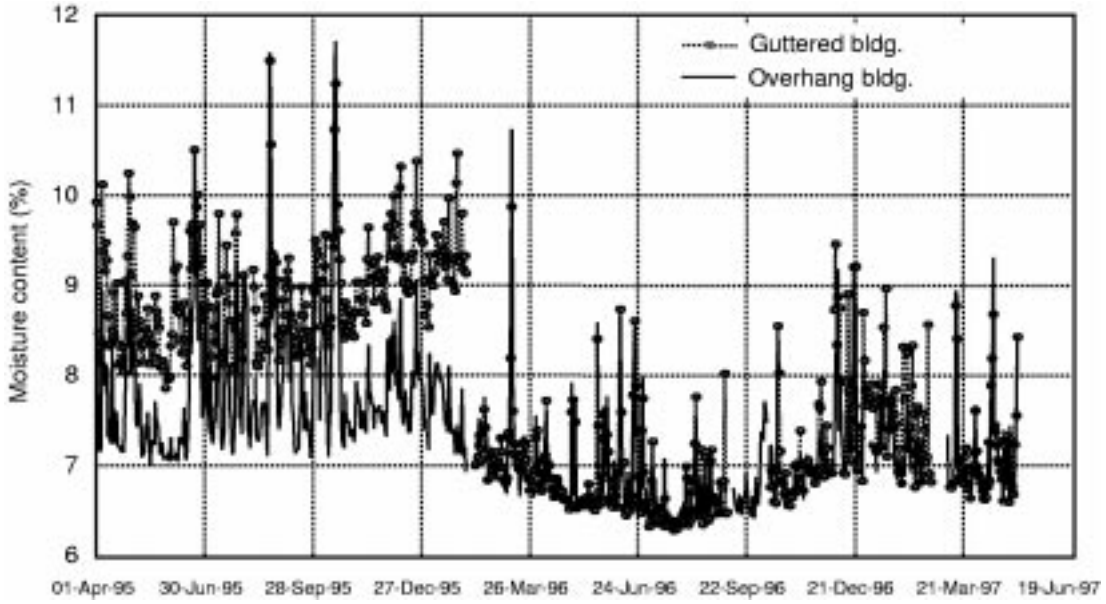

Figure 50—Daily average moisture content of factory-finished siding without back-priming (NF) on both buildings for April 1, 1995, through May 5, 1997.

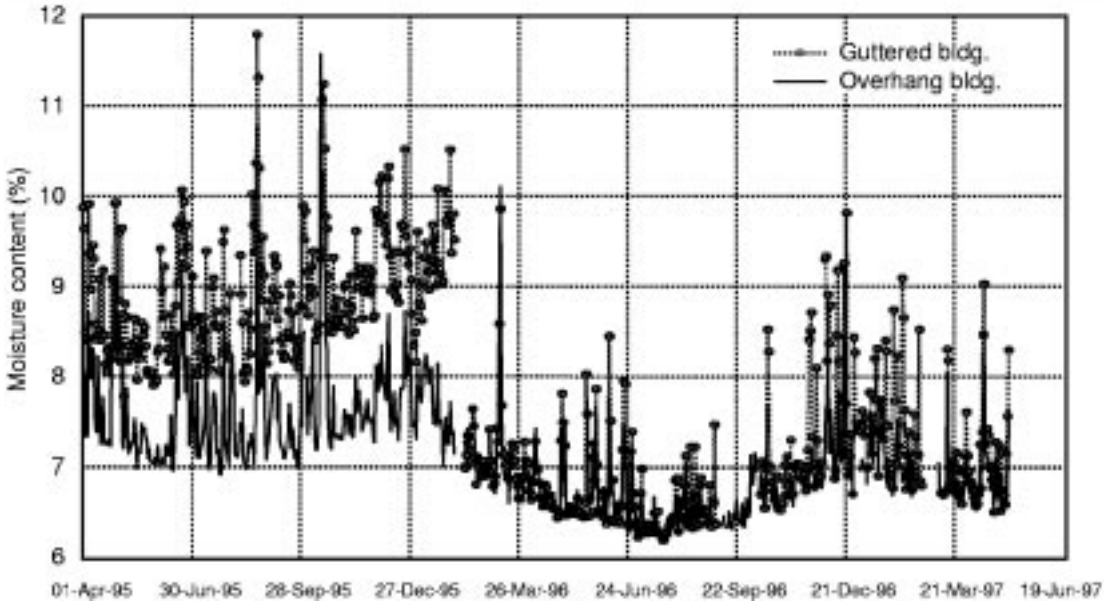

Figure 51—Daily average moisture content of siding on walls with plywood sheathing and polyolefin weather barrier (PT) on both buildings for April 1, 1995, through May 5, 1997.

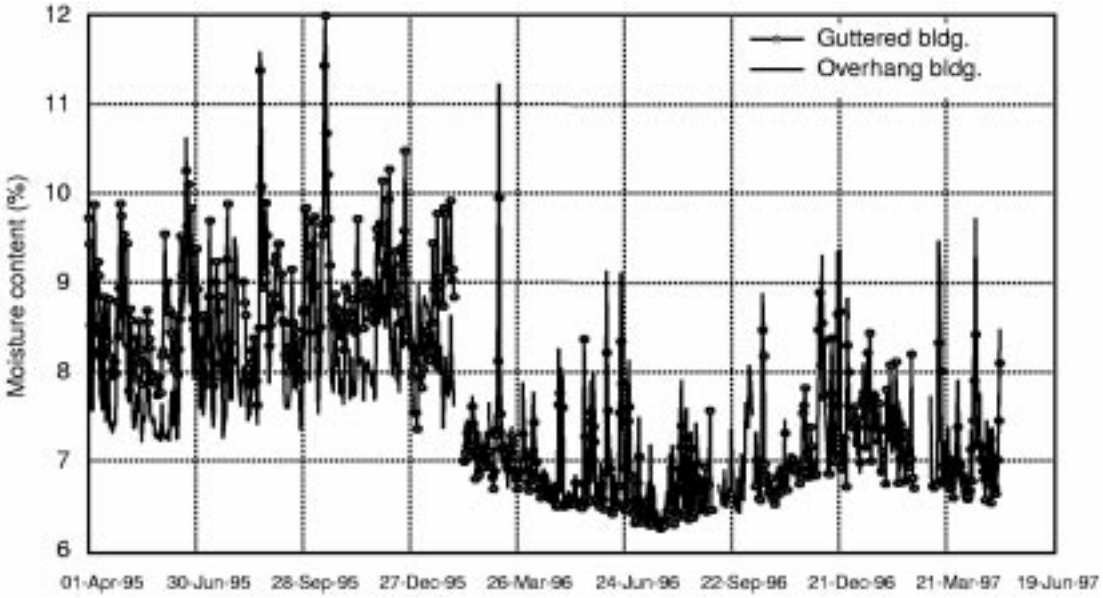

Figure 52—Daily average moisture content of siding on walls with plywood sheathing and felt (PF) on both buildings for April 1, 1995, through May 5, 1997.

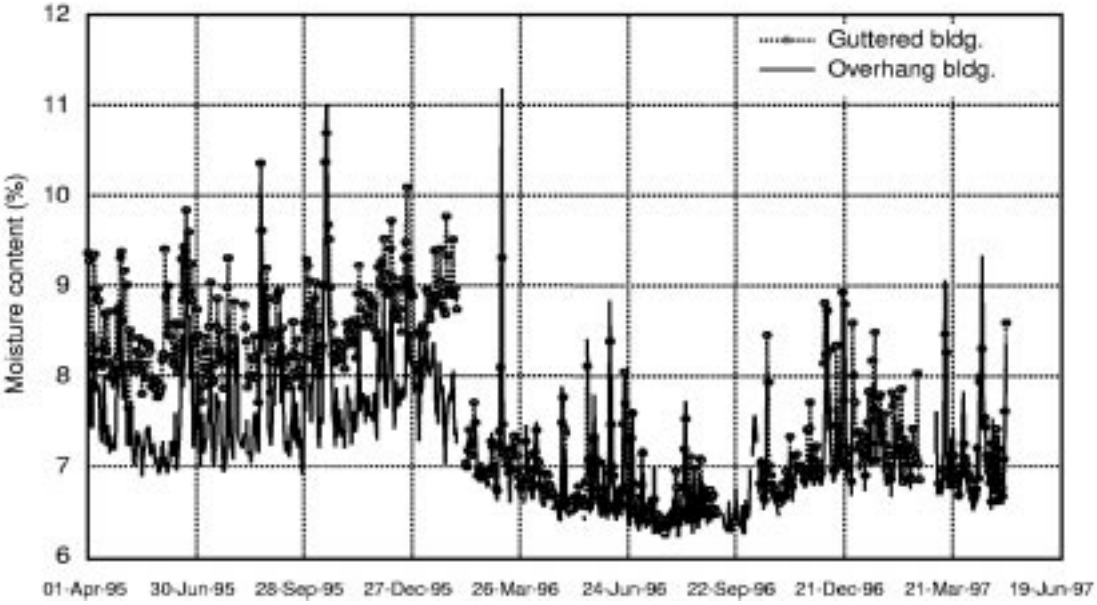

Figure 53—Daily average moisture content of siding on walls without sheathing (open) with felt (OF) on both buildings for April 1, 1995, through May 5, 1997.

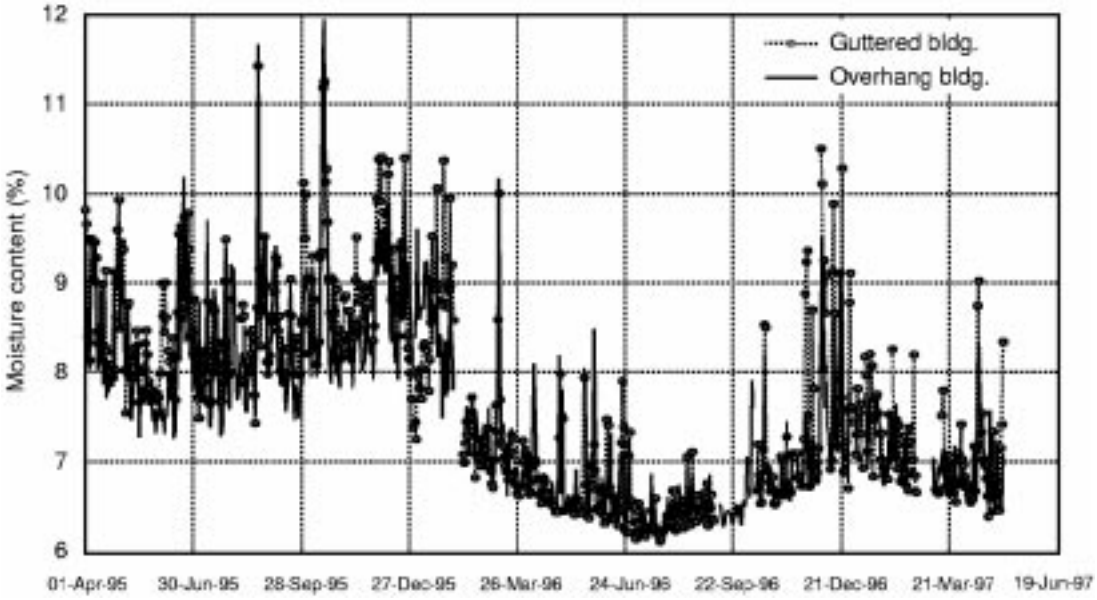

Figure 54—Daily average moisture content of siding on northeast-facing walls on both buildings for April 1, 1995, through May 5, 1997.

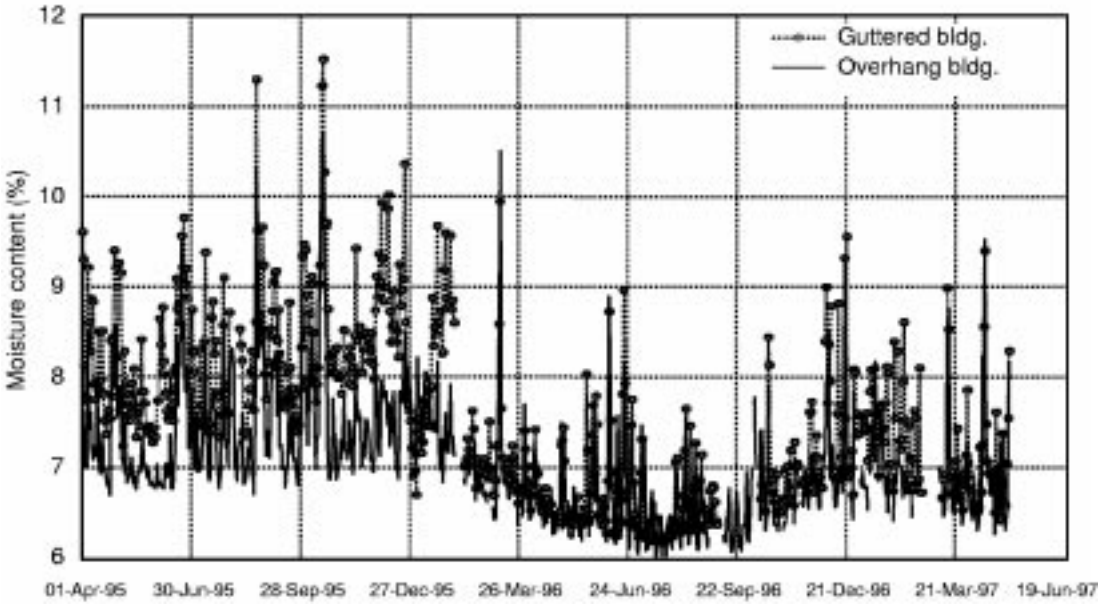

Figure 55—Daily average moisture content of siding on southeast-facing walls on both buildings for April 1, 1995, through May 5, 1997.

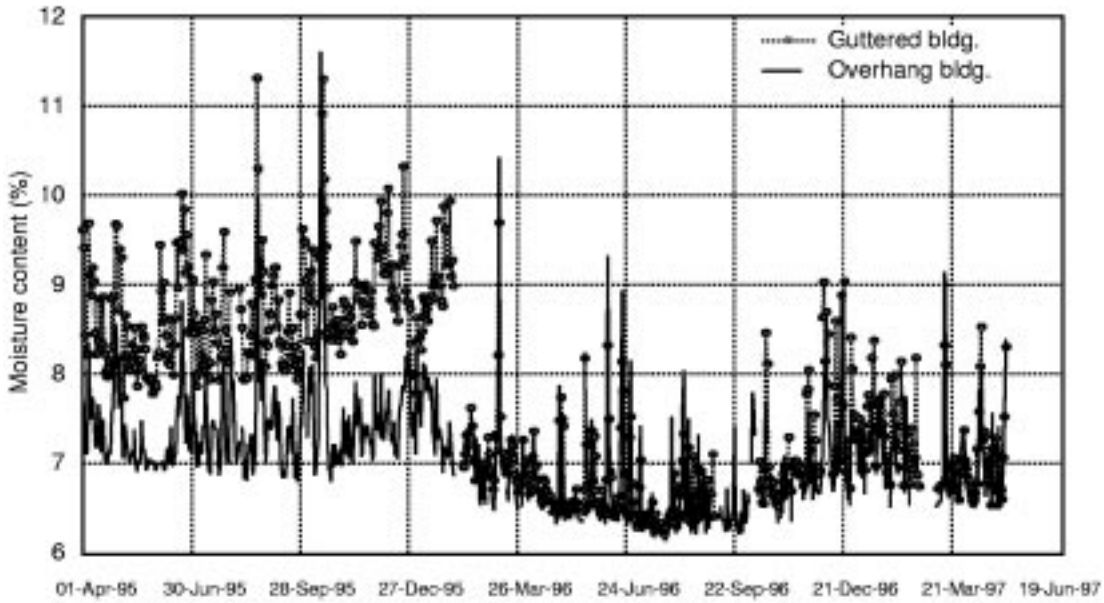

Figure 56—Daily average moisture content of siding on southwest-facing walls on both buildings for April 1, 1995, through May 5, 1997.

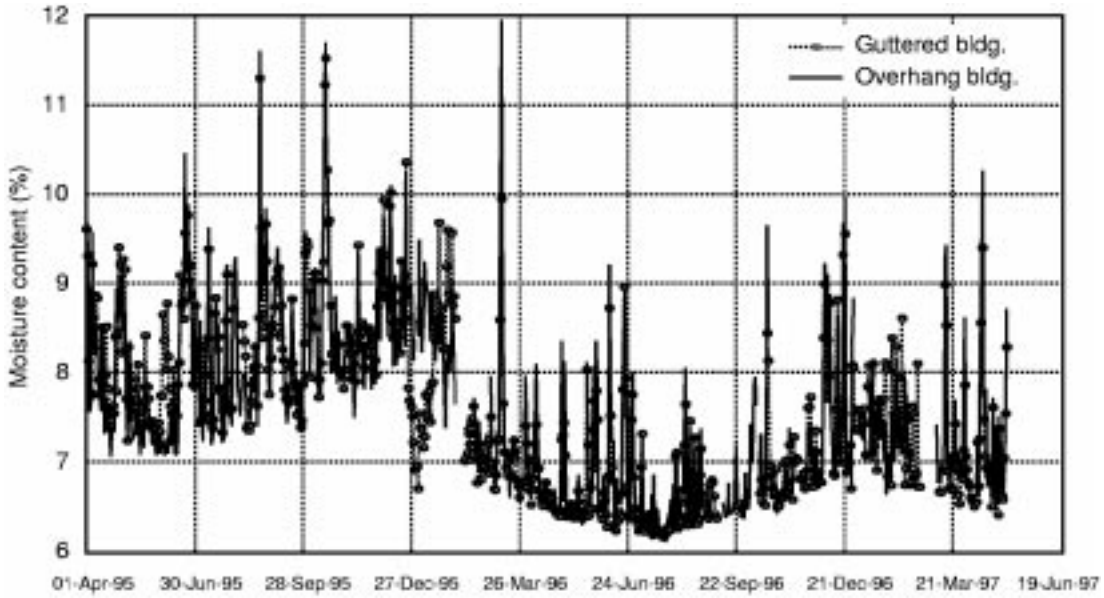

Figure 57—Daily average moisture content of siding on northwest-facing walls on both buildings for April 1, 1995, through May 5, 1997.

Results of Laboratory Measurements

Linear Expansion

Linear expansion of the specimens ranged from 0.21% to 0.27%, well within the maximum 0.40% specified in the ANSI/AHA standard. The mean linear expansion was 0.23% with a sample standard deviation of 0.016%. There was no apparent influence of finish system on linear expansion, indicating that the measurements were indeed taken at equilibrium.

Residual Thickness Swell

Residual thickness swell after reconditioning to 50% RH averaged 4.3%, substantially less than the maximum allowable of 20% specified in the product standard. Average residual thickness swell in the first batch of 24 specimens was 4.6%, and in the second batch, it was 4.0%.

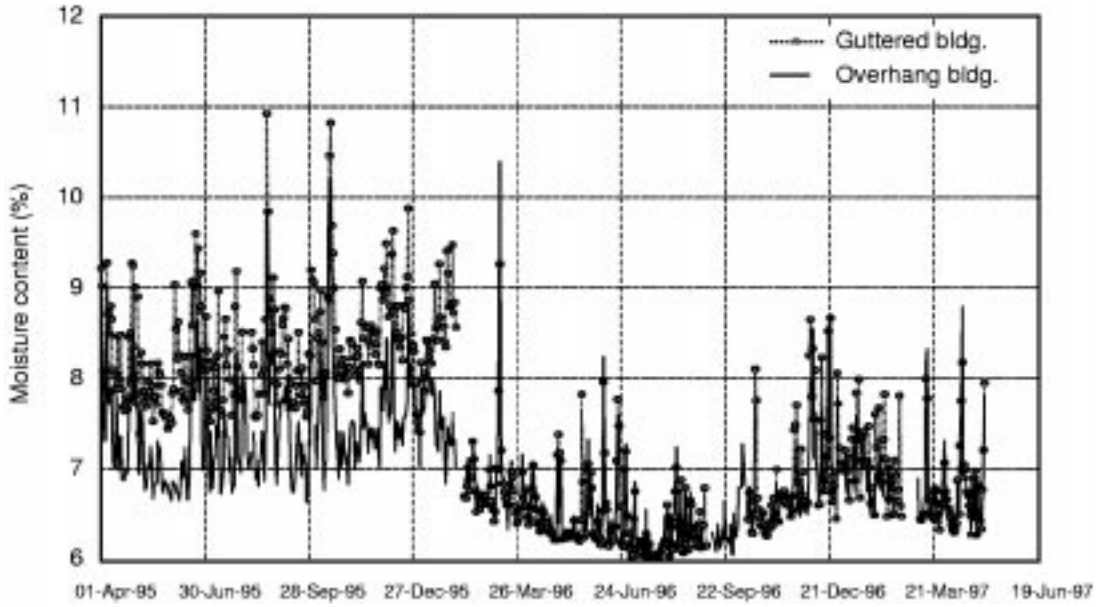

Figure 58—Daily average moisture content of bottom boards on both buildings for April 1, 1995, through May 5, 1997.

Because standard deviations of residual thickness swell within each batch were 1.3% and 1.6%, there is no statistical difference between these two batches.

Lateral Nail Resistance

We conducted lateral nail resistance tests on 578 siding specimens following slightly modified ASTM D 1037 procedures. A summary of the results is shown in Table 12.

Although the average values for the unexposed siding are slightly higher, they cannot be statistically differentiated from the exposed samples. Further categorization by wall orientation and finishing treatment did not reduce the standard deviation in the data and did not produce consistent and significant differences between groups. We therefore conclude that the 2½-year exposure did not significantly reduce the lateral nail resistance of the siding.

Table 12—Average lateral nail resistance of siding before and after exposure on the buildings

	Average lateral nail resistance (kN (lb))[a] at three distances from edge of board		
	6.3 mm (1/4 in.)	9.5 mm (3/8 in.)	12.7 mm (1/2 in.)
Unexposed siding	1.93 [0.20] (433 [45])	1.96 [0.17] (441 [38])	2.14 [0.20] (480 [46])
Guttered building	1.80 [0.15] (405 [33])	1.85 [0.18] (415 [40])	2.05 [0.18] (461 [41])
Overhang building	1.82 [0.16] (410 [36])	1.87 [0.20] (420 [44])	2.00 [0.16] (449 [36])

[a]Standard deviation shown in brackets for both units.

Discussion

This study involved only lap siding from one particular mill. The quality of this siding as measured with several tests (Table 1) was very high, especially compared with the industry minimum standards for hardboard siding. The applicability of our results is therefore limited to siding from that particular mill and cannot be extended to other hardboard siding without additional information about the properties of that particular siding. Siding with similar properties should give similar performance. The 29 months of exposure was also too short to use the results of this study to draw broad conclusions about the long-term durability of hardboard siding in this climate. However, the 29 months of exposure had no significant effect on the condition of the siding.

The final MCs of the siding were below 8%, and the hourly data show that this was typical for the entire 29 months of exposure. The siding showed no deterioration after 29 months of exposure. The MC data of the trim and the outdoor humidity and rain gauge measurements show that the building was exposed to a great amount of rain and very high humidity conditions. It appears that the siding did not absorb liquid rainwater and was essentially in moisture equilibrium with the surrounding air, especially on the north-facing walls, while some of the wood trim was more prone to absorbing rainwater.

The final MC data showed that boards facing south were drier than boards facing north, and the in-place thickness measurements provide us with a weak indication that at least the southeast-facing boards were indeed drier throughout the test.

At the time of removal, boards without back-priming tended to be drier than boards with back-priming. However, these differences did not necessarily exist during the entire 2½ years of the test. The hourly MC data did not provide us with the ability to check if these differences existed throughout because all the MCs were too close to the lower limit of the measurement system. The full coverage of primer on the backs of back-primed specimens apparently retarded drying of the siding through the back surfaces. This is supported by the drying curves for 203-mm (8-in.) squares of siding specimens with and without back-priming (Figs. 59 and 60), which show that specimens without back-priming dried more rapidly than back-primed specimens of similar size, at either 103°C (217°F) or 27°C (81°F). The temperature of siding in direct sunshine on the test buildings was between these two levels.

Figure 60 illustrates the effect of back-priming under cyclical conditions. We placed four 203-mm (8-in.) specimen squares (retrieved from the test buildings) in humidity rooms and monitored their MC. The rooms were at 27°C (80°F) and at 30% and 90% RH, respectively. Samples remained in one room for 2 weeks and were then moved to the other room. Figure 60 shows drying and wetting curves for the first full exposure cycle, along with MCs at the ends of the 2-week exposure periods during the second cycle. Figure 60 shows that back-priming can significantly retard both vapor sorption and desorption, that is, back-priming retards both wetting and drying. Our site-collected data suggest that unusually heavy rains occurred in the months prior to removal and dry weather occurred for the week prior to removal. In light of this, it seems likely that back-primed siding had a slightly but consistently higher MC at time of removal because it had not yet fully dried out. However, all the siding, including that not back-primed, had at least some primer or paint coverage on the back at the laps.

The in-place thickness measurements provided us with a weak indication that NS boards experienced the least thickness swell for most of the period, but the thickness swell data for the NF boards are more ambiguous. Taken together, the final MC data and thickness swell data support the conclusion that back-priming this type of hardboard siding did not result in lower MCs and may have been somewhat counterproductive.

The MC data for the siding do not show an effect of wall construction type or a difference between the overhang building and the guttered building. However, the inspection of the windows and the final MCs of the trim strongly suggest that, while gutters provide protection from rain on the sidewalls, overhangs provide additional protection because of their presence on the gable ends.

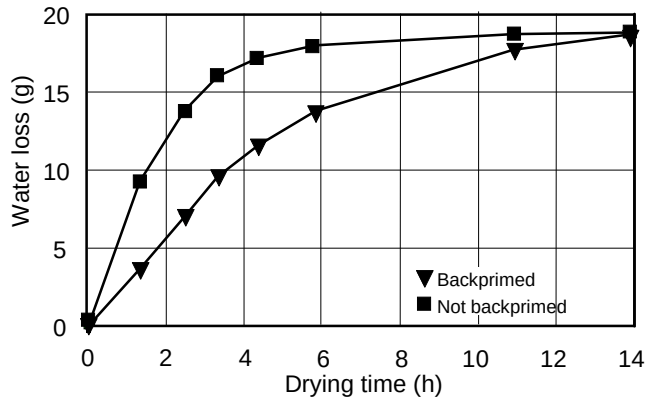

Figure 59—Weight loss compared with drying time of 203-mm (8-in.) squares of siding at approximately 7% initial MC in drying oven at 103°C.

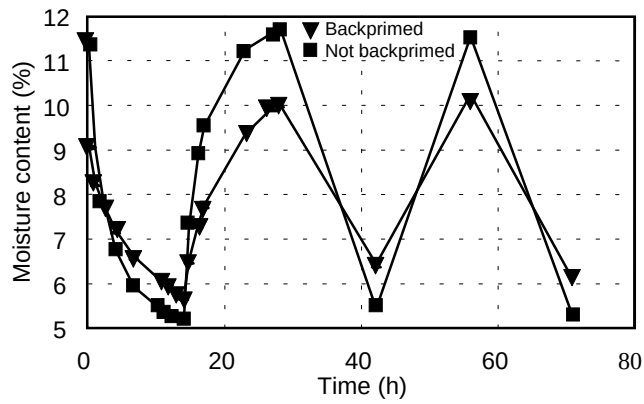

Figure 60—Average moisture content of siding with and without back-priming when exposed cyclically to 30% and 90% RH.

It has been argued in recent years that, to properly function as a rain screen, wood-based siding should be spaced out from the sheathing and ventilated to provide air pressure equalization. The pressure data in this report suggest that conventionally installed lap siding provides substantial air pressure equalization. An air space may still be beneficial, primarily because it probably provides better drainage of any water that penetrates to the back of the siding (especially around windows and doors). An air space would reduce the chance of this water penetrating the weather barrier and wetting the sheathing.

Wind pressures across the two intensively monitored wall sections were predominantly exfiltrative (that is, inside pressure was higher). Infiltrative pressures only occurred in the wall sections near the windward corner. This generally only happened for short periods of time because wind direction continually varied. We found that our measured pressures were considerably different from published pressure data based on wind tunnel experiments.

Conclusions

Our conclusions apply only to siding from one particular mill and cannot be extended to other hardboard siding without additional information about the properties of that siding.

- The siding was in excellent condition after 29 months of exposure to southern Florida weather conditions. Weather during the test period was typical for that area, which means that it presented an extreme decay hazard for wood on the exterior of buildings. The MC of the siding remained low at around 8% or lower. There was no appreciable difference in lateral nail resistance (measured near the drip edge) between unexposed boards and boards that were on the building for 2½ years.
- There is no evidence that back-priming this siding lowered in-service moisture content.
- Siding on south-facing walls tended to be slightly drier.
- The type of wall construction or weather barrier had no detectable effect on MC of the siding.
- The MC of the solid wood trim on the gable ends was lower on the overhang building. The data also suggest that gutters, when functioning properly, can provide protection of wood trim on sidewalls similar to that of overhangs. There also was evidence that the overhangs significantly reduced water leakage behind the window trim. There was no difference in siding MC between the two buildings.
- There was evidence of water leakage behind the window trim below more than half of the windows on the guttered building. The leakage occurred between the window unit and the bottom trim, even though the trim was carefully caulked with high-quality caulking. Leakage was due to caulk adhesion failure. The leakage had not led to decay of the siding or elevated siding MC at the time of siding removal.
- In-place thickness swell on the drip edge of the siding was less than 3%.
- We found no decay in redcedar trim but did find decay in a pine doorjamb on the guttered building. In May 1997, the MC of the wood trim was generally between 9% and 12%, but we found several locations with MCs greater than 20%.
- The lap siding provided substantial air pressure equalization across the siding.
- There was evidence of air leakage past the top plate into the wall cavity. This air bypassed the weather barrier and created larger than expected air pressures across the gypsum board. This air leakage led to periods when the cavity was pressurized with respect to both the inside and outside.
- Wind-induced air pressures across the exterior walls were predominantly exfiltrative, even on the windward side of the building. Infiltrative pressures only occurred near windward corners of the building during short periods of time. We found that actual pressures were considerably different from published pressure data that were based on wind tunnel experiments.

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