United States
Department of
Agriculture

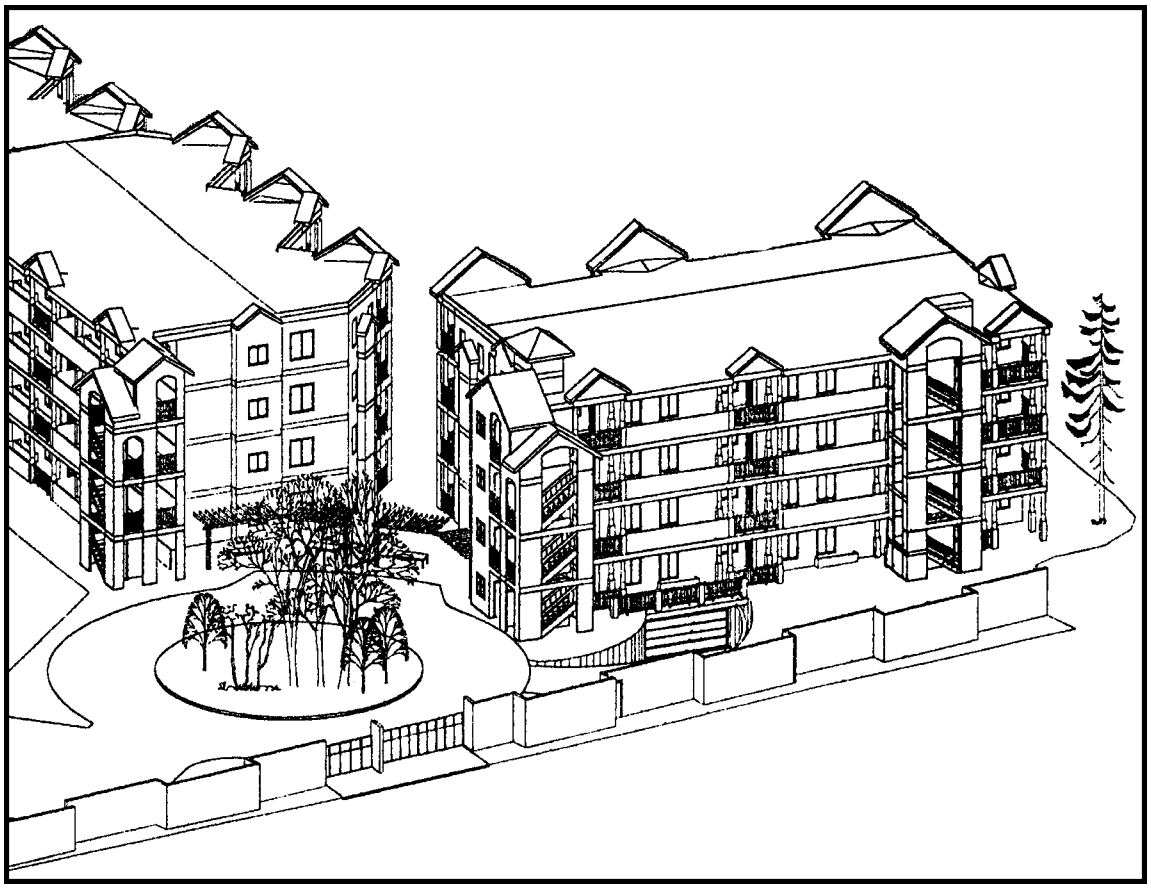
Forest Service

Forest
Products
Laboratory

General
Technical
Report
FPL–GTR–142

Evaluating Wood-Based Composites for Incipient Fungal Decay With the Immunodiagnostic Wood Decay Test

C. A. Clausen
L. Haughton
C. Murphy



Abstract

Early and accurate detection of the extent of fungal deterioration during forensic inspection of the building envelope would eliminate excessive or unnecessary replacement of wood-based building materials. Areas of water infiltration in wood-framed building envelopes in the Pacific Northwest were evaluated visually and sampled for moisture content. Wood samples were cultured in the laboratory and tested for the presence of decay fungi by the immunodiagnostic wood decay (IWD) test. In oriented strandboard sheathing, a correlation was seen between low moisture content, arrested fungal growth, advanced visual deterioration, and negative IWD results in a building envelope in which advanced fungal decay was discovered 3 years prior to the evaluation. Evaluation of exterior siding showed a correlation of high moisture content and of swelling and softening of the product with positive IWD results. We conclude that the IWD test should be used to indicate the presence of decay fungi in areas where high moisture content indicates a potential for biodeterioration, since moisture is a precursor for fungal growth.

Keywords: immunodiagnostics, oriented strandboard, incipient fungal decay

Contents

December 2003

Clausen, C.A.; Haughton, L.; Murphy, C. 2003. Evaluating wood-based composites for incipient fungal decay with the immunodiagnostic wood decay test. Gen. Tech. Rep. FPL-GTR-142. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 7 p.

A limited number of free copies of this publication are available to the public from the Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53726–2398. This publication is also available online at www.fpl.fs.fed.us. Laboratory publications are sent to hundreds of libraries in the United States and elsewhere.

The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin.

Cover: Artist's rendering of condominium complex in Seattle, Washington.

Evaluating Wood-Based Composites for Incipient Fungal Decay With the Immunodiagnostic Wood Decay Test

C.A. Clausen, Microbiologist
Forest Products Laboratory, Madison, Wisconsin

L. Haughton, Senior Associate
C. Murphy, Principal
Exterior Research and Design, Seattle, Washington

Introduction

Methods for detecting the early stages of fungal decay in wood include tests for mechanical strength (i.e., compression test or modulus of elasticity), electrical conductivity (e.g., moisture meter, x-ray), acoustic detection (e.g., acoustic emission, stress-wave time), chemical analysis, and laboratory detection (e.g., culturing, microscopy, serological tests). Culturing and microscopy are currently considered the only definitive methods for detecting incipient wood decay.

One type of serological test, the immunodiagnostic wood decay (IWD) test, utilizes anti-xylanase antibody to detect minute quantities of an extracellular fungal enzyme from a sample of wood shavings (Clausen and Green 1996). The enzyme, β-1,4-xylanase, is a hemicellulase produced by decay fungi very early in the decay process (Green and others 1989). Because hemicelluloses are rapidly removed by brown-rot fungi during the initial stages of colonization, detecting the presence of the hemicellulase ß-1,4-xylanase with anti-xylanase antibody indicates the presence of active fungal growth (Clausen and others 1991).

The IWD method has been shown to detect brown-rot decay fungi prior to wood weight loss or strength loss as measured by maximum compression strength, modulus of elasticity, and modulus of rupture (Clausen and others 1991, Clausen and Ferge 1995, Clausen and others 2001, Clausen and Kartal 2003). In laboratory soil–block tests on solid wood, the IWD test can detect the presence of xylanase 3 to 5 days after inoculation with decay fungi. In a laboratory test on dimension lumber, the IWD test detected the presence of fungal xylanase up to 60 cm away from the culturable fungal infection (Clausen and Ferge 1995). In field studies on solid wood, the IWD test detected the presence of fungal xylanase up to 100 cm away from the culturable fungal infection.

The objective of the study was to determine if the immunoassay for incipient fungal decay can detect fungal enzyme in oriented strandboard (OSB) with the same sensitivity as it does in solid sawn wood.

Typical moisture and degradation conditions encountered in the Pacific Northwest during evaluations of wood-framed structures may be categorized into five broad types:

- Type 1—No visible staining or deterioration; <22% moisture content (MC)
- Type 2—Surface deterioration and/or localized high moisture level (generally <30% MC). Surrounding sheathing generally appears good, although water stain may appear on sheathing below localized moisture. Typically, no deterioration or excess moisture is expected at underlying wood framing.
- Type 3—Broader and deeper area or areas of deterioration; larger area or areas of excess moisture (>30% to 40% MC). Physical probing of surrounding sound sheathing reveals continued high resistance (i.e., panel strength); however, moisture movement (e.g., staining) is more apparent and extensive swelling of sheathing panel may be detected. Some moisture infiltration into underlying framing is expected.
- Type 4—Localized severe deterioration; larger areas of excess moisture (>40% MC). More extensive replacement of sheathing panel and framing is assumed.
- Type 5—Extensive and severe deterioration. Extensive underlying structural deterioration is expected.

For decay to occur in oriented strandboard (OSB), as in solid sawn wood, a source of moisture is needed. The two most common sources of water infiltration in wood-framed structures in the Pacific Northwest are (1) flashing and sealing deficiencies at window perimeters or similar wall penetrations and (2) deck perimeter and deck parapet-to-wall transitions.

Materials and Methods

Two field evaluations were conducted at a condominium complex in Seattle exhibiting water infiltration conditions. The condominium complex was constructed in 1997. The winter of 1998–1999 was the wettest on record for Seattle: 86 cm (34 in.) of rain was recorded between November 1 and February 28 (National Weather Service, Seattle). In 1999, a forensic investigation of the building envelope[1] revealed extensive decay in the complex.

For the evaluation of flashing or sealing deficiencies at window perimeters, a wall was deconstructed beneath a window opening by removing the wood siding, asphalt-saturated building paper, exterior gypsum sheathing, and underlying OSB sheathing to reveal the wood framing members. During deconstruction, moisture conditions were documented and OSB and framing members were sampled for decay tests and identification. Samples of visibly decayed OSB were cultured on 2% malt agar.

To investigate the effect of water filtration through deck perimeter and deck parapet-to-wall transitions, a laminated veneer lumber (LVL) deck frame, supporting deck post, and OSB rim board were evaluated. After visual inspection, moisture readings and samples of wood shavings were obtained to test for fungal decay by immunoassay.

A third field evaluation was conducted on two exterior siding products in a Seattle shopping center constructed in 2000. One product was 19-mm (3/4-in.) tongue & groove (T&G) cedar siding abutted to flashing over a concrete sill. The other product was 12.7-mm (1/2-in.) composite-type siding abutted to a concrete walkway.

In each evaluation, IWD test results were compared to visual assessment, moisture content readings, and fungal culture results.

IWD Test

Samples of wood shavings were obtained by drilling with a 6.4-mm drill bit and collecting sawdust for testing from selected sampling sites. The drill bit was cleaned between samples to prevent sample carryover. Fifty-milligram samples of wood shavings were extracted for 1 to 2 h in 2 mL deionized water containing 0.01% Triton X-100 at 25°C. Following extraction, each fluid was tested by immunoassay for the presence of decay fungi (Clausen and others 1991, Clausen 1994, Clausen and Green 1996). The IWD test results were recorded as positive (+) or negative (–), as indicated on pertinent figures. Results shown on figures correlate with sampling sites.

Moisture Content Measurement

Moisture readings were taken with a Delmhorst (Delmhorst Instrument Co., Towaco, New Jersey) moisture meter. Numerical meter values are indicated on the figures.

Adhesive Analysis

Adhesive type was analyzed in selected structural panels using a para-dimethylaminocinnamaldehyde stain for detecting aliphatic nitrogen in adhesives (Schriever 1981).

Fungal Culture

Mold fungi were cultured and identified by Lab/Cor, Inc. (Seattle, Washington). Fungal mycelium was cultured on 2% malt agar and identified by Fungal and Decay Diagnostics (Black Earth, Wisconsin).

Inductively Coupled Plasma Analysis

Elemental analysis of selected structural panels was conducted according to AWPA A21–00 (AWPA 2001).

Results and Discussion

Window Perimeters

In the condominium complex, the area evaluated was directly beneath a window opening of a stair tower at the west elevation of a building. The primary exposures to wind and rain are from the south and east elevations. The window opening lacked flashing, and the underlying building paper had gaps in coverage as well as a "reversed" (bottom to top) lap. Together, these construction practices had led to water infiltration from the window opening into the wall cavity below, contributing to extensive wetting of the underlying gypsum and OSB sheathing as well as an adjacent LVL header. The stain pattern from water infiltration that crossed three OSB sheets revealed extensive damage to only the two outer sheets; the middle sheet was not damaged (Fig. 1a).

Removal of the sheathing and subsequent analysis, including identification of "mill stamps" on the back of the panels, showed that two types of OSB were installed at this area during construction. Inspection confirmed that both types of OSB panels had been installed prior to siding installation and final inspection of the structure. Samples of the two panel types were analyzed for predominant wood type, adhesive type, and additives, such as fungicide (Table 1).

Fungal growth on the gypsum board and decayed OSB panel showed extensive hyphal fans covering most of the area coinciding with the water infiltration stain pattern.

[1] A building envelope is the continuous and integrated system of exterior weatherproofing elements at roofs, walls, and foundations that provides resistance to unintended moisture infiltration and thermal energy transfer.

Figure 1—Oriented strandboard (OSB) sheathing beneath window opening. (a) Numerals indicate moisture content (MC) measurements. IWD results recorded as positive (+) or negative (–). (b) Arrows indicate interface between decay and mold fungal growth.

Table 1—OSB panel characteristics

Panel	Decay status	Predominant wood	Adhesive type	Additives[a]
1[b]	Sound	*Betula* sp.	Urea fomaldehyde	—[c]
2[d]	Extensive	*Populus* sp.	Diphenyl methane diisocyanate	—[c]

[a]Analysis by inductively coupled plasma spectroscopy.
[b]Figure 1a-left.
[c]None detected.
[d]Figure 1a-right.

There was a distinct line of demarcation between the fungal hyphae and extensive mold growth, as indicated by the arrows in Figure 1b. The mold was identified as *Stachybotrys chartarum*. The visible decay fungus was not culturable from the mycelial sample, but *Paecilomyces*, a common mold fungus, was repeatedly cultured and identified in the area of visible decay.

The IWD test does not react with *Paecilomyces* (Clausen and Ferge 1995). Wood can be too decayed to recover a culture of viable fungus or to give positive IWD results. In the case of advanced decay, where all wood components are involved, decay fungi eventually stop growing, whereas mold fungi produce copious spores that last for many years and can germinate whenever conditions are favorable. Both mold fungi and decay fungi require adequate moisture to initiate growth (Clausen 2002).

Framing members (Hem–Fir 2 by 4 lumber[2]) had been set directly on concrete, where perpetual wicking of moisture could occur. Advanced decay was visible on either end of the framing members directly beneath the decayed OSB panel. Surface mycelia were present on the entire face of the framing members when in contact with decayed OSB. Beneath the sound OSB panel, extensive decay was noted only where the framing members were in direct contact with concrete.

Metal analysis indicated no significant difference between Panels 1 and 2 in composition. The level of iron in Panel 2 was elevated, a common occurrence in decayed wood. Decay fungi act like a pump, hydrolyzing woody substrates via the Fenton system and pushing soluble minerals ahead of the fungal hyphae into the wood (Koenigs 1974).

Sampling sites are indicated in Figures 1 to 3. Moisture readings are correlated to positive IWD test results in Table 2.

Immunoassay results were negative, even on visibly decayed OSB. Despite obvious Type 2, 3, and 4 deterioration, moisture content was uniformly below 20%, indicating a prolonged period of drying. The xylanase enzyme detected by the IWD test is somewhat resistant to denaturation by heat and drying because of a 50% carbohydrate coating (Green and others 1989), but this enzyme will denature over long periods of drying, possibly months or years. Dry conditions in excess of 2 years have been shown to result in negative IWD test results in decayed wood, indicating denaturation of the indicator enzyme (unpublished results). Results of a laboratory test on water-saturated OSB held at 70% relative humidity (RH) showed that OSB lost moisture at a rate of 10.8%/week (n = 14), until reaching equilibrium after 4 weeks at 43% moisture by weight. This demonstrates that once OSB is water saturated, it dries slowly.

[2] Nominal 2 by 4 in. (standard 38 by 89 mm).

Figure 2—MC measurement (20%) and IWD test results at sampling sites in framing beneath decayed OSB sheathing.

Figure 3—Results at sampling sites in LVL header and door framing under window opening.

Simulations of hygrothermal performance of wall systems in Seattle conducted by Karagiozis (2002) showed that during periods of increased moisture, OSB initially tends to resist increased moisture sorption; however, during periods of drying, wet OSB tends to resist moisture desorption. Haughton and Murphy (2003) conclude that the inner and outer layers constituting the OSB panels do not work in concert when excess moisture moves to the exterior surface. They attribute these sorption and desorption performance properties to the perpendicular orientation of the inner wood strands of the panel; the decreased density of the inner layers resulting from the hot press process used to manufacture OSB; and, in part, to the small amount of wax added to improve the resistance of OSB to moisture and water absorption (Structural Board Association 1996).

Table 2—Representative results: moisture content, visual evaluation, fungal culture, and IWD test

Evaluation	Fig. no.	MC[a] (%)	Mycelium visible	Fungal culture[b]	IWD
Window perimeter	1	16–18	Yes	*Paecilomyces*	+
Deck parapet	4	15	No	ND	+
	6	17	No	ND	+
	6	22	Yes	ND	+
	7	20	Yes	White-rot	–
	7	15–16	No	ND	+
Siding	9	30	No	ND	+
	9	23	No	ND	+

[a]Moisture content.
[b]ND is not determined.

In our laboratory study, 70% RH was selected as a typical humidity for the Pacific Northwest. However, records for 12 months prior to the December 2002 sampling indicated that the total rainfall recorded in Seattle was 81 cm (32 in.), more than 13 cm (5 in.) below normal. The summer months that preceded the sampling were the driest on record for Seattle, with less than 5 cm (2 in.) of rain recorded in a 4-month period. Furthermore, recorded rainfall during 2000 was more than 20 cm (8 in.) below normal; the winter of 2000–2001 was recorded as the second driest on record (National Weather Service, Seattle, Washington).

The combination of visible but nonviable decay fungus, low MC readings, prolonged dry climatic conditions, and negative IWD test results suggests denaturation of the enzyme detected by IWD. Even in areas of high moisture, the complex nature of the OSB matrix may have prevented enzyme movement along the grain of the wood.

The structure of OSB may also limit dispersal of the enzyme by prohibiting continuous moisture movement along the grain of the wood. Moisture movement along the grain is many times faster than that across the grain. Active fungal growth produces a host of decay initiators, which may more readily enable movement of the indicator enzyme through the continuous matrix of solid wood.

Figure 4—Results at two sampling sites in LVL deck frame.

Figure 5—Results at two sampling sites in deck post.

Deck Perimeter and Deck Parapet Transitions

A large area of a white-rot decay fungus was discovered on the OSB rim board covering the LVL deck frame. The fungus, isolated as a single-spore isolate of a white-rot fungus, could not be identified to genus. Sampling sites are indicated on Figures 4 to 7, and test results are compiled in Table 2.

Figure 6—Results at sampling sites in OSB-sheathed deck frame and rim board.

Figure 7—Results at sampling sites in backside of OSB sheathing over LVL deck frame (see Fig. 6).

Exterior Siding

Visual inspection showed that painted 19-mm (3/4-in.) cedar T&G siding was abutted to flashing over a concrete sill. Moisture content of the siding was high (30%) at 25.4 mm (1 in.) from the bottom as a result of moisture wicking from the concrete sill as well as poor water drainage away from the building (see Fig. 8). Moisture content was 16% at 152 mm (6 in.) above that sampling site. Visual evaluation of the exterior siding did not reveal fungal growth. Cedar is naturally resistant to fungal decay (Simpson and TenWolde 1999). Abutting the T&G siding to the concrete sill plate raised the product above grade and may have inhibited moisture uptake.

Visual inspection of the 12.7-mm (1/2-in.) composite siding showed that this product was in direct contact with the concrete walkway. A moisture content of 23% and positive IWD test results were seen up to 305 mm (12 in.) above the baseboard. Composites may resist initial moisture uptake, but chronic exposure to moisture eventually results in water

Figure 8—Results at sampling sites in tongued and grooved exterior siding.

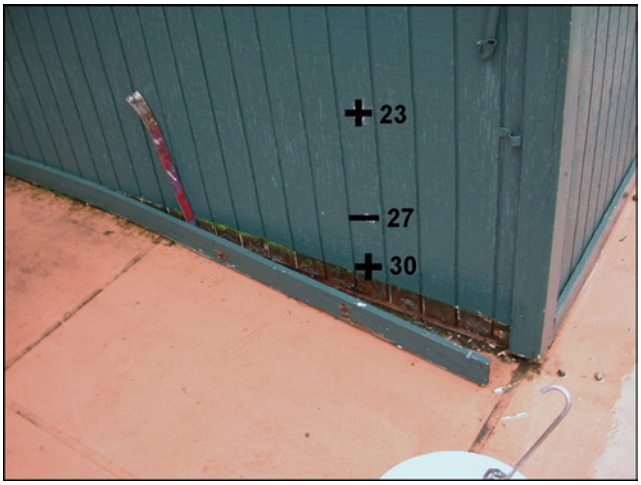


Figure 9—Results at sampling sites in exterior composite siding abutted to poorly drained concrete walkway.

wicking and swelling of the composite product, increasing the likelihood of decay.

Removal of a base rim board revealed that the composite siding had been finished after the rim board was installed (Fig. 9). Behind the rim board, the product had softened and moss was growing from water saturation. Samples were taken at 25.4, 152, and 305 mm (1, 6, and 12 in.) from the bottom of the rim board with corresponding moisture readings of 30%, 27%, and 23%, respectively. Results are shown in Figure 9 and Table 2.

Concluding Remarks

Water infiltration was the primary cause of wood deterioration in all three field evaluations in Seattle, Washington. Evidence of fungal growth was extensive in OSB and framing members in the field evaluations at the condominium complex. Extensive decay was associated with flashing and sealing deficiencies at window perimeters or transitions between deck perimeter and deck parapet-to-wall transitions. Despite obvious advanced decay that had been discovered in 1999, a majority of moisture content readings were below 20%, probably the result of prolonged dry climatic conditions in 2000–2001 and 2002. We believe that the time elapsed since initial discovery of advanced decay combined with the duration of dry weather accounts for the high number of negative IWD test results. Laboratory tests in a controlled environment are needed to better assess movement of the extracellular indicator enzyme in the OSB matrix.

Visual evaluation of exterior siding did not reveal fungal growth in the cedar T&G siding. The moisture content of this siding was high near its base, but the sampling sites were negative for the IWD test. The moisture content of the composite siding was 23%. The composite siding had positive IWD test results up to 305 mm (12 in.) above the baseboard.

Based on the results of this study, we conclude that the IWD test should be used as a tool in areas with high moisture content (above 22%). Fungal growth may be inactive for an undetermined amount of time, especially when moisture readings are below 20%, resulting in inactivation of the indicator enzyme for the IWD test. Where there is visible fungal growth in conjunction with high moisture, the IWD test can be used to determine the extent of decay beyond the visible fungal growth in solid wood. Further studies are needed to evaluate the ability of the IWD test to track fungal enzyme movement in composite products.

Literature Cited

AWPA. 2001. Standard method for the analysis of wood and wood treating solutions by inductively coupled plasma emission spectrometry. A21–00. Woodstock, MD: American Wood Preservers' Association. 313–317.

Clausen, C.A. 2002. Recognize, remove, and remediate mold and mildew. In: Proceedings of the 2nd annual conference on durability and disaster mitigation in wood-frame housing; 2000 November 6–8; Madison, WI. Madison, WI: Forest Products Society: 231–234.

Clausen, C.A.; Ferge, L. 1995. Dimensional lumber model demonstrates the sensitivity of the particle capture immunoassay in early detection of brown-rot fungi. International Research Group on Wood Preservation IRG/WP/95–20058.

Clausen, C.A.; Green, F. III. 1996. Method and apparatus for immunological diagnosis of fungal decay in wood. US Patent # 5,563,040.

Clausen, C.A.; Kartal, S.N. 2003. Accelerated detection of brown-rot decay: comparison of soil block test, chemical analysis, mechanical properties, and immunodetection. Forest Products Journal. 53:11/12.

Clausen, C.A.; Green, F., III;. Highley, T.L. 1991. Early detection of brown-rot decay in southern yellow pine using immunodiagnostic procedures. Wood Science and Technology. 26: 1–8.

Clausen, C.A.; Ross, R.J.; Forsman, J.W.; Balachowski, J.D. 2001. Condition assessment of roof trusses of Quincy Mine Blacksmith Shop in Keweenaw National Historical Park. Res. Note FPL–RN–0281. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 4 p.

Green III, F.; Clausen, C.A.; Micales, J.A. [and others]. 1989. Carbohydrate-degrading complex of the brown-rot fungus *Postia placenta*: Purification of β-1,4-xylanase. Holzforschung. 43(1): 25–31.

Haughton, L.; Murphy, C. 2003. Moisture exchange performance of OSB and plywood structural panels. RCI Interface, Raleigh, NC. Journal of Roof Consultants Institute. 21(6): 6–13.

Karagiozis, A.N. 2002. Building enclosure hygrothermal performance study, Phase 1. ORNL/TM–2002/89.

Koenigs, J.W. 1974. Hydrogen peroxide and iron: A proposed system for decomposition of wood by brown-rot Basidiomycetes. Wood and Fiber. 6(1): 66–80.

Schriever, E. 1981. Stain for detecting aliphatic nitrogen in adhesives/coatings. Holz alsRoh- und Werkstoff. 39: 227–229.

Simpson, W.; TenWolde, A. 1999. Physical properties and moisture relations in wood. In: Wood handbook: Wood as engineering material. Gen. Tech. Rep. FPL–GTR–113. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 318 p.

Structural Board Association. 1996. Binders and waxes in OSB. Tech. Bull. 118. Ontario, Canada: Standard Board Association. http://www.osbguide.com