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Condition Assessment of the Northern Climatic Research House at the USDA Forest Service, Forest Products Laboratory

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Abstract

In 2001, a northern climatic research house was constructed to demonstrate advanced and novel building techniques, materials, and systems for the Upper Midwest region of the United States. As part of the Advanced Housing Research Center program, the house highlighted energy efficiency, sustainability, water efficiency, and moisture research, specifically moisture movement and accumulation in buildings. The house is a 2,300-ft^2, two-story structure located on the grounds of the USDA Forest Service, Forest Products Laboratory (FPL) in Madison, Wisconsin. It is considered a research structure and not part of FPL's building inventory. Following construction, the house was heated and cooled but not occupied. However, its structural condition has become a concern and visitation has consistently diminished throughout the years. In May through July 2023, a visual and minimally invasive condition assessment was performed on the house. This report details the findings of that assessment and focuses on existing or potential problem areas. Compliance with the Americans with Disabilities Act is also addressed in this report, and conclusions and recommendations from the condition assessment are given to assist with future decision-making.

Keywords: Condition assessment, visual inspection, decay, moisture

Contents

Conversion table

English unit	Conversion factor	SI unit
foot (ft)	3.048×10^{-1}	meter (m)
inch (in.)	2.54×10^{1}	millimeter (mm)
pound, force (lbf)	4.448222	newton (N)
square foot (ft^2)	9.2903×10^{-2}	square meter (m^2)

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Condition Assessment of the Northern Climatic Research House at the USDA Forest Service, Forest Products Laboratory

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Introduction

In 2001, a northern climatic research house (Fig. 1) was constructed to demonstrate appropriate and novel building techniques and materials for the Upper Midwest region of the United States (Williamson and others 2010). The house is located on the grounds of the USDA Forest Service, Forest Products Laboratory (FPL) in Madison, Wisconsin. The house is considered a research structure and not part of FPL's building inventory. Following construction, the house was heated and cooled but not occupied. Regular (sometimes daily) tours were conducted starting when the house opened and continuing until about 2008, at which time tours had diminished to less than one per week. After regular tours ended, the house was used occasionally for special events, intermittent tours, and storage. Since the time of construction, only minimal and reactive maintenance has been performed on the house.

In May through July 2023, the structural condition of the house was assessed. Specifically, a detailed visual inspection of the timbers and other wood structural elements was conducted from May 31st through June 2nd, 2023. The house was approximately 22 years old at the time of this assessment. This report details the findings of the assessment with a focus on areas in need of maintenance, repair, or replacement. The condition assessment was performed in support of a joint venture agreement (23-JV-11111133-025) between FPL and Mississippi State University (MSU).

As with any public asset, determining highest and best use for this structure and the land on which it sits is complex. For this determination, questions such as those subsequently noted are being considered. Given the nature of federal budgeting, programming, and planning, these questions must be considered for 5-, 10-, and 20-year time frames.

The following are examples of the types of questions being asked to help determine the course of action for the research house:

- What is the next highest value associated with the land on which the house is located?
- If the house is removed, what other types of research programming could be conducted on the site?
- If the house is removed, what other types of demonstration programming could be conducted on the site?
- If kept, how can the utility value of the structure be increased?
- If kept, what are the future research program and funding opportunities associated with the house?
- If kept, what are the future demonstration program and funding opportunities associated with the house?
- What research opportunities could be gleaned with its deconstruction?
- If kept, what level of financial investment is needed to repair (today) and maintain (into the future) the structure?
- What are the limitations of the visual assessment described in this report; that is, what are the risks and potential costs associated with latent or hidden decay or deterioration that was undetectable in the course of this relatively noninvasive assessment?

This report provides a portion of the technical information that may be used in addressing some of these questions.

Figure 1—Northern climatic research house (originally called the Research Demonstration House) and the sign that is located near the front of the house (inset photo) (photos property of Mississippi State University, used with permission).

History of the Building

Creation

The northern climatic research house was originally called the Research Demonstration House and was created as part of the Advanced Housing Research Center (AHRC) (Williamson and others 2010). AHRC was a national effort to promote wise use of wood in construction. During the course of the AHRC program, multiple structures were proposed and built in the United States. An analogous house (the southern climatic test house) was built on the MSU campus in Starkville, Mississippi, to demonstrate appropriate and novel techniques and materials for use in the southern climatic region of the United States.

The northern climatic research house, constructed in 2001, is a 2,300-ft^2, two-story structure that is based on a standard architectural design and was built to represent a typical midwestern house.

Location

The house is located on the grounds of the USDA Forest Service, Forest Products Laboratory in Madison, WI. The physical address for the facility is 1 Gifford Pinchot Drive, Madison, WI, 53726 (Fig. 2).

Purpose

The northern climatic research house demonstrated building techniques that were appropriate for this region at the time of construction. As part of the AHRC program, energy efficiency, resource conservation, and durability were highlighted. The house was originally conceived to conduct full-scale research studies on moisture management

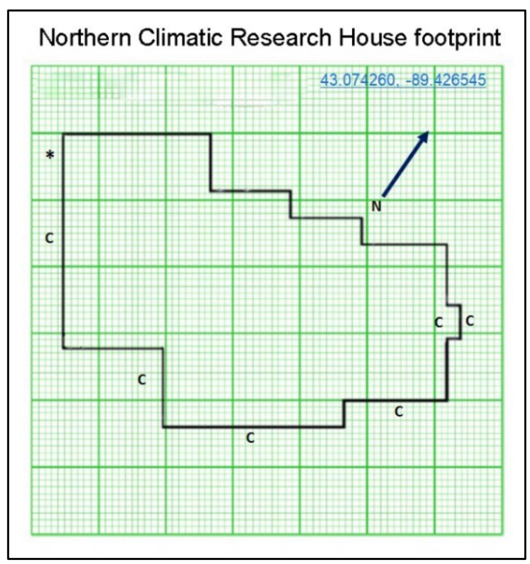

Figure 2—Footprint of the research house with GPS coordinates and cardinal direction north indicated. The letter C indicates conditions present for future intrusion of wood-destroying insects if not addressed, and * indicates where a drain is emptying near an underground electrical supply (image property of Mississippi State University, used with permission).

practices in a cold climate region. At the time of construction and still to this day, moisture and mold are significant national issues, and research is needed to educate builders and consumers on the best recommended practices to minimize adverse moisture effects on the structure and indoor living environment.

Materials

The house incorporates a variety of solid, engineered, and composite wood materials. It highlights the use of wood in residential construction. Wood species used in the house vary. Solid, engineered, and composite wood materials appear to have come from all over North America. The structural materials such as wall studs and other solid framing, engineered wood I-joists, and roof sheathing are grade-stamped appropriately.

Predecessor

For more than 100 years, FPL has been involved with wood-framed housing research and demonstration. In 1930, a previous research house was built on the grounds of FPL, near the site of the research house built in 2001. As the research concluded and the contemporary demonstration value of the 1930 house wrapped up, it was removed. Williamson and others (2010) stated “the FPL housing research program is dynamic, and changes may occur periodically that affect the nature of the research and the appearance of the structures.”

Visual Inspection

An in-depth, nondestructive visual inspection of the house was conducted in late spring 2023. Accepted inspection techniques commonly used for wood structures are detailed in Ross and others (2024). The simplest method for locating deterioration in wood members, elements, and assemblies is visual inspection. For this method, an inspector observes the structure for signs of actual or potential deterioration, noting areas that require further investigation. Visual inspection is useful for detecting intermediate or advanced surface decay, water damage, mechanical damage, or failed members. Visual inspection cannot detect early-stage decay or deterioration or any internal defects hidden from view.

Several key indicators are looked for in visual inspections: fruiting bodies (evidence of advanced decay), staining or discoloration of members (indicators of water intrusion and subsequent damage), evidence of insect activity (pin holes, frass, and powder posting), plant or moss growth in a member, deep checks or splits, failed or missing members, and foundation settlement.

During the visual inspection of the wood members in the northern climatic research house, specific attention was given to the following:

1. Evidence of water intrusion and subsequent damage, especially where the wood members make contact with the foundation, are exposed to exterior conditions, are exposed to persistent or prolonged moisture or water leaks, or otherwise appear compromised

2. Evidence of existing or imminent structural failure of wood members, timbers, panels, and subassemblies

3. The accessibility ramp

4. The back stoop, guardrail, and stairs

5. The front porch stair treads

6. The exterior cladding (siding)

7. The roof

During the visual inspection, basic carpentry tools such as flat head screwdrivers, hammers, and tape measures were used to probe suspect areas and to quantify measurements. In addition to trained persons, graduate students also participated in this condition assessment. As such, the condition assessment exercise and subsequent reporting provided a hands-on experiential training opportunity for graduate students who participated throughout.

Inspection Findings

Back Entrance

The back entrance stoop, leading into the kitchen, is cause for imminent concern. The back deck presents some wood decay. The joists are connected to the joist box (also called rim joist) with appropriate hangers, but the joist box, which carries the load of the joists, is not well connected to the support post (Fig. 3). This joist-box-to-post connection system is not sufficient.

For safety, rail and guard systems are required on decks that are 30 in. or more off the ground. Rail and guard systems are supposed to resist a 200-lb lateral load applied at any location (International Residential Code, Section R312, R312.1.1 (ICC 2017)). At the back entrance stoop of the research house, the deck height is 41 in. (Fig. 4). In addition,

Figure 3—Joist-box-to-rail connection of back entrance deck showing insufficient fixity (photo property of Mississippi State University, used with permission).

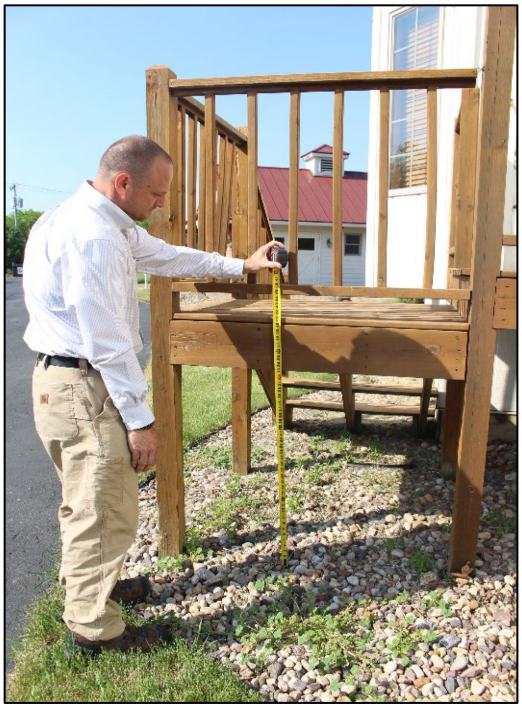

Figure 4—Measuring the back entrance deck height to see if it is up to code (photo property of Mississippi State University, used with permission).

the rail-to-post connections have completely failed in several locations (Fig. 5). This failure renders the guard system unable to resist any loading. It appears that the rail-to-post connections were initially and inadequately connected with nonstructural #4 or #6 finish nails. This connection detail probably contributed to the guard system failure. It is recommended that this stair/stoop structure be immediately and actively closed to prevent any use until it can be replaced.

Also, the storm door leading from the kitchen to the stoop is deteriorated beyond repair (Fig. 6). In its current state, it is not functioning as needed, that is, as a means of preventing water infiltration into the structure. Replacement of the storm door appears to be the only option to restore its intended functions of energy savings and protection from water intrusion.

Accessibility Ramp

The accessibility ramp is severely deteriorated. The structural posts, carrying beams, deck boards, and rails are all deteriorated to some degree. Some of the deck boards have deteriorated to the extent that they can be removed by hand and are at risk of bending failure (Fig. 7). Many of the structural posts are decayed at their cores and hollowed out to the extent that they do not securely hold the rails. In many cases, the rails can be lifted off the posts (Fig. 8). The rails were let-in to the posts by mortise and tenon type construction. The mortise pockets appear to have served as water traps. As a result, the tops of the posts are severely decayed to a depth of approximately 12 in. or more. As such, the posts are no longer able to hold or remain fixed to the handrails. In many cases, the handrail boards are also decayed, particularly at the ends. Some of the support cross beams that are affixed to the posts and support the deck framing are severely deteriorated in their cores (Fig. 9).

In sum, the posts, carrying beams, decking, and handrails are severely decayed and need immediate replacement. Because many of the deck boards, many of the support beams, the structural posts, and the handrails are severely deteriorated, the structure must be closed and actively blocked. Two of the three entrance points to the ramp (the

Figure 5—Rail-to-post connections of the back entrance have completely failed in the highlighted locations (photos property of Mississippi State University, used with permission).

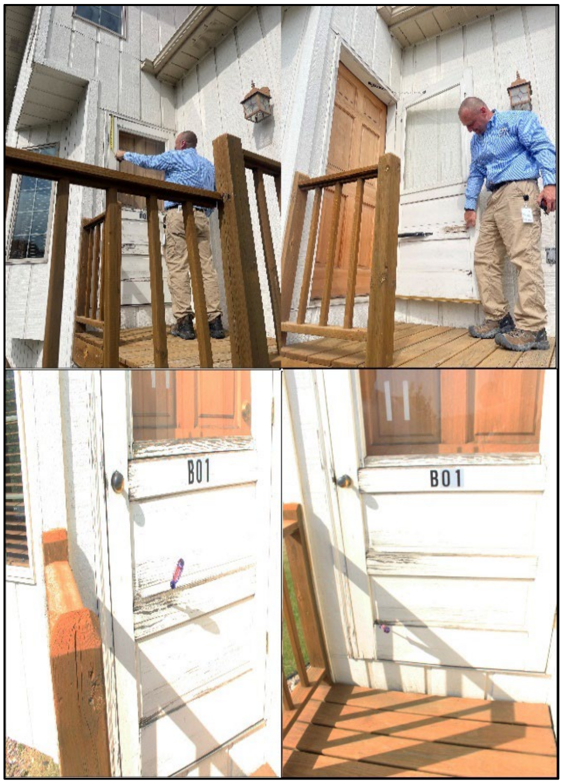

Figure 6—Storm door on the back stoop is deteriorated (photos property of Mississippi State University, used with permission).

Figure 8—Rail-to-post connections in the accessibility ramp were severely decayed. The rail can be removed from the post, and the post was also decayed. When the post was probed with a screwdriver, the screwdriver went in easily (photos property of Mississippi State University, used with permission).

Figure 7—Deteriorated deck boards in the accessibility ramp. Some of the deck boards could be removed without effort (photo property of Mississippi State University, used with permission).

Figure 9—Advanced decay in carrying beams that support the floor frame of the accessibility ramp (photo property of Mississippi State University, used with permission).

two along the paved driveway) are posted “closed” and blocked with rope (Fig. 10). One of the three entrance points to the ramp (the location where the ramp connects to the front porch) is open (Fig. 11). This entrance point should also be actively blocked and posted as closed to prevent pedestrian access to the ramp.

Front Entrance

The front entrance deck rail posts have decay. A screwdriver was inserted into the top of the post to probe the extent of the decay (Fig. 12). The bottom of the post appeared to be connected to the stair stringer with screws. This method of post fixity is not considered sufficient to provide the 200-lb resistance as required by the building code (International Residential Code, Section R312, R312.1.1). The stair treads are decayed. Screwdrivers were inserted into the decayed portions to probe the extent of the deterioration (Fig. 13). The front porch flooring near the top of the steps has become unfastened because of fastener corrosion and rust, and post trim is showing signs of deterioration (Figs. 14 and 15). It is recommended that the front porch steps, posts, rail, and guards be replaced and the front porch decking be refastened or repaired as necessary. The guard and railing system of the front porch are fastened with small (approximately 4d) finish nails, similar to that of the back stoop. This fastening system is inadequate and should be replaced. The condition of the front porch ceiling tongue and groove boards indicates that the porch takes on moisture (Fig. 16).

Interestingly, with major deterioration closing the entrance ramp, decay and failure of the front posts and treads, and the immediate need to close the rear steps and stoop because of fastener and other failures, at present, there is no safe means of entering or exiting the research house.

Figure 10—“Closed” sign and rope barricade at one of three entrance points to the accessibility ramp (photo property of Mississippi State University, used with permission).

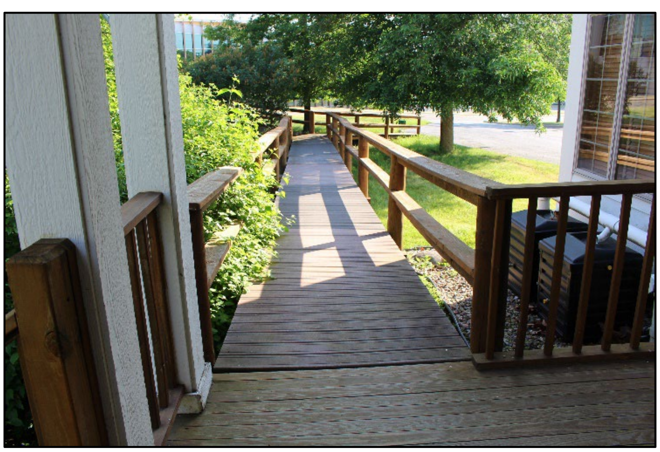

Figure 11—Front porch entrance point to the accessibility ramp, which should be posted as “Closed” and actively blocked to prevent pedestrian access (photo property of Mississippi State University, used with permission).

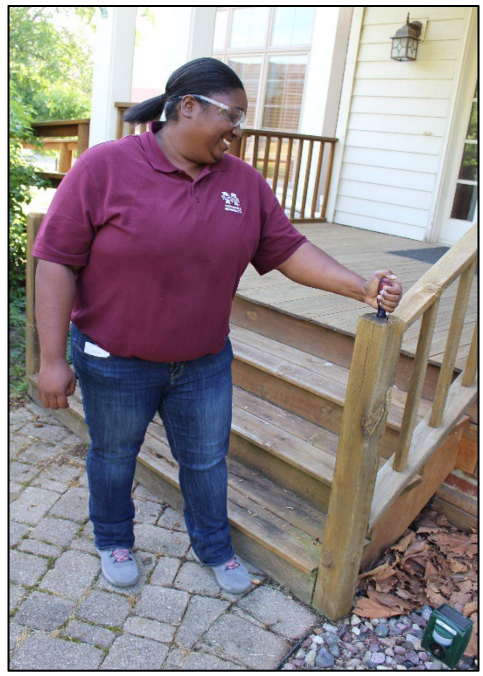

Figure 12—A screwdriver was easily inserted into the front entrance deck rail post, showing the extent of the decay (photo property of Mississippi State University, used with permission).

Figure 13—Screwdrivers were inserted into the decayed portions of the steps to the front porch, showing the extent of the deterioration (photos property of Mississippi State University, used with permission).

Figure 14—The front porch flooring near the top of the steps has become unfastened due to fastener corrosion (photo property of Mississippi State University, used with permission).

Figure 15—Front porch post trim showing signs of deterioration (photo property of Mississippi State University, used with permission).

Figure 16—Tongue and grove ceiling of the front porch is swelling, indicating moisture issues (photo property of Mississippi State University, used with permission).

Siding and Roof

Most of the siding (cladding) on the house is Texture 1-11 (also known as T1-11) plywood. There is also 8-in.-wide oriented strandboard (OSB) lap siding as well as stucco and brick veneer in small areas and on some wall portions. The T1-11 siding is failing due to decay in places along the southeast and southwest sides of the house. The worst location is in the vicinity of the dining room particularly near the triple-mullion dining room window (Figs. 17 and 18). The siding under and around this window needs replacement. In other places, the siding is beginning to rot, particularly at the lower-most edges of the various T1-11 panels. These bottom edges often become water traps that don't readily drain and dry. There is decay in the vicinity of an electrical LB conduit body penetration on one of the southwest walls. Some of this decay may be accelerated

Figure 17—Location of worst siding deterioration beneath and in the vicinity of the triple mullion dining room window (photo property of Mississippi State University, used with permission).

Figure 18—Deteriorated siding under the dining room window (photo property of Mississippi State University, used with permission).

because of shade from a large tree located in close proximity to the exterior siding (Fig. 19). The shade from the nearby tree prevents and/or retards redrying of the siding after rain events, leaving the walls wet longer than walls that are in full sun and thereby accelerating decay.

During the inspection, an approximately 18- by 48-in. section of T1-11 siding was removed from under the dining room triple mullion window unit (Fig. 20). The house wrap and flashing beneath the siding appeared intact and functional. The sheathing was probed by striking it with a hammer (Fig. 21). The sheathing appeared intact based on the hammer's sound and return bounce upon striking. Therefore, it is assumed that the wall framing beneath the sheathing in this area is also intact and not decayed. Siding in other areas where utilities are attached are showing similar signs of decay (Fig. 22) and some trim boards are showing signs of decay that was caused by paint failure (Fig. 23).

Figure 19—Large cedar tree in close proximity to the house (photo property of Mississippi State University, used with permission).

Figure 20—Section of T1-11 siding removed from beneath the triple mullion dining room window (photo property of Mississippi State University, used with permission).

Figure 21—A hammer was used to gently strike the sheathing to probe for decay and deterioration (photo property of Mississippi State University, used with permission).

Figure 22—Areas where utilities are attached are showing similar signs of decay (photo property of Mississippi State University, used with permission).

Figure 23—Trim boards around the house are showing signs of decay due to paint failure (photo property of Mississippi State University, used with permission).

If the decision is made to keep the structure, then repair and replacement of the siding is necessary. Another consideration is that the only portion of sheathing that was evaluated was under the decayed 18- by 48-in. section of siding that was removed. This section accounts for less than 1% of the clad area. The extent to which sheathing and potentially wall framing in the other 99+% of the wall area may be impacted by water intrusion and its negative effects on the wood is unknown.

The roof shingles appear to be hand-split cedar shakes but are actually made from a wood–plastic composite material, the plastic of which came from recycled plastic milk containers. From the exterior, it is noticeable that the roof shingles are puckering (also known as buckling or lifting) in many areas (Fig. 24). Densified and compressed composites swell when exposed to moisture over prolonged periods. This swelling causes adjacent shingles to push on each other and ultimately lift off the roof structure. On the front side of the house, over the garage door and porch entry, it appears that both the shingles and the roof sheathing are lifting from the roof framing. As the shingles pucker and lift or separate from the roof, their ability to resist wind and shed wind-driven rain decreases. Similarly, when roof sheathing swells and lifts from the roof framing, it loses its ability to shed wind-driven rain. The intrusion of rain ultimately leads to deterioration within wood framing. In the research house, water damage was noted in the main stairwell between the first and second floors. This damage appears as a small blackish colored hole at the top of the stairwell ceiling, with rust colored splash marks beneath the hole. This moisture intrusion appears to be coming from a hole or penetration in the roof. Also, the shingles are showing signs of biological growth, which is an indication of water being held on the surface of the shingles (Fig. 24).

Figure 24—Shingles showing signs of weathering, such as biological growth and puckering (photo property of Mississippi State University, used with permission).

During the course of the condition assessment, no shingles were removed for inspection of the roof sheathing and truss/rafter roof framing. Additionally, from the attic, the roof framing and sheathing at the eaves, over the garage, and elsewhere were inaccessible. As such, given the appearance of the puckered shingles and swelled sheathing, it is safe to assume that there is some level of water-intrusion-related damage to the sheathing and framing. As such, repair and replacement of at least a portion of the roof sheathing and framing should be included in any type of roof repair cost estimation.

Foundation

Weathering issues related to moisture from rain and snow are apparent around the house. Visible inspection from the exterior shows weathering, splitting, and warping of preservative-treated wood foundation members. Although these wood members are not visibly decayed, the extensive splitting and warping creates paths for moisture ingress. Additionally, in several places, fastener (galvanized nails) withdrawal was evident. Fastener withdrawal is not uncommon when smooth shank nails are used in wood members that cyclically shrink and swell. The extent to which fastener withdrawal has reduced the overall capacity of the foundation system of the research house is unknown.

The soil around the house's foundation may be creating other issues. Signs of fracture or buckling of the drywall can be seen in Figure 25. A corresponding unleveling in the basement could explain this drywall buckling (Fig 26a and b). Deconstruction of the basement floor would be needed to further investigate the issue. This may be from soil erosion from rain and moisture; soil erosion can be seen in front of the garage (Fig. 26c).

Figure 25—A fracture or buckling of sheet rock in the great room. The right-side header inside the great room shows fracture or buckling in the drywall above the door opening. This may correspond to soil settling or foundation movement on the left side in the basement (photos property of Mississippi State University, used with permission).

Figure 26—Signs of settling in the foundation in the southwest portion of the basement (a and b) and in front of the garage (c). The treated plywood foundation shows unleveling underneath the left side pier supporting the left side great room wall (a and b). This may have been caused by water movement under the foundation. Other indications of water can be seen in the soil unleveling under the pavers located near the front left side of the garage approach (c) (photos property of Mississippi State University, used with permission).

The disconnected downspout (Fig. 27), located at the front of the house, near the location where the accessibility ramp connects to the porch, is a possible contributor to the foundation/soil settling issues. The downspout is supposed to be connected to a water collection and drainage device. However, because it is disconnected, rain from the roof is being collected by the gutters, transferred through the downspout, and deposited immediately adjacent to the foundation at this location.

The lifespan of preservative-treated wood is finite. Given the visual findings with respect to wood foundation members splitting and warping, fasteners withdrawing, and soil settling, further and more invasive investigation is recommended. To better assess the current condition of the wood foundation, careful removal of some portion of the basement flooring and wall coverings to inspect the floor joists, wall studs, and sheathing is necessary. If the condition is sound, then the flooring and/or wall covering could be replaced. If decay and/or other degradation is found, then repair should be planned as needed. As a matter of priority, foundation wall framing on the front side of the house, where water runoff tends to travel toward the house and soil shifting was noted, should be evaluated.

Figure 27—Disconnected downspout near location where ADA accessibility ramp connects to the front porch (photo property of Mississippi State University, used with permission).

Effect of Decay on Mechanical Properties of Wood

The presence of deterioration caused by decay has a significant effect on various properties of structural timbers. Table 1 summarizes the findings of early scientific literature on this topic.

Americans with Disabilities Act Compliance

The house is not compliant with the Americans with Disabilities Act (ADA). At present, there is no means of safely accessing the house. To achieve ADA compliance, the ramp must be replaced.

Inside the house, many of the door openings are 32 in. wide. To achieve ADA wheelchair compliance, these need to be widened to 36 in. Additional major ADA compliance issues include but are not limited to the need for an elevator or chair-lift to access the basement and top floor, upgrading the bathrooms and fixtures, installing grab-handles as needed, and changing door hardware throughout as needed.

Code-based required headroom through doorways and passages is generally 6 ft 8 in. Based on that, there is not adequate headroom in the stairway leading to the basement. This low headroom area is demarked with yellow and black caution tape. The low headroom may be cause for a building inspector or code official to deny a certificate of occupancy. Because the low headroom situation is caused by the location of a structural beam, there is not an easy fix for the problem.

Conclusions and Recommendations

The following conclusions and recommendations are based on our visual inspection of the northern climatic research house:

1. The accessible entrance ramp is deteriorated beyond repair. Two of its three entrance points are closed and need to remain closed until it can be replaced or removed. The third entrance point, on the porch, should be closed to prevent pedestrian access to the ramp.
2. The back (kitchen) entry steps and stoop need to be closed immediately. The deterioration of some of the

stair treads, under-designed joist-box-to-post installation, and failed rail/guard system present a potentially unsafe situation. This structure should remain closed until it can be replaced or removed.

3. The front porch steps (treads) and posts are deteriorated. These require replacement.
4. Taken together, the decay or disrepair associated with items 1, 2, and 3 result in no safe means of entering or exiting the structure at present.
5. The siding on the southeast and southwest sides of the house needs repair and/or replacement.
6. The roof shingles are puckering in many places because of irreversible moisture-induced swelling. This puckering has led to roof leaks. One such leak is noted inside the house at the ceiling of the main stairwell. If the decision is made to keep the building, the roof shingles will need to be replaced. Given the house’s age (approximately 22 years), entire roof replacement, rather than piecemeal patching, is recommended.
7. Roof replacement cost estimation should also consider the potential need for some portion of sheathing and framing repair, given the visibly swollen sheathing previously noted.
8. Additional more-invasive evaluation of the wood foundation, including removal of a portion of the basement flooring and wall coverings to access the treated wood framing, is recommended.
9. A significant amount of work is needed to make the house ADA compliant.

In the opinion of the authors, the research house has served its research and demonstration purposes. The active research programs related to the house have been completed. Although the demonstration purpose is ongoing, as building materials and construction techniques develop and advance and the house ages, the contemporary demonstration value of the house decreases.

Table 1—Estimated values for strength losses in softwoods and hardwoods at early stages of decay (indicated by weight loss) by brown-rot and white-rot fungi as a percentage of the value for nondecayed samples[a,b]

Approx. weight loss (%)	Strength property loss (%)										
			Static bending								
	Toughness	Impact bending	General bending strength	Work to max. load	MOR[c]	MOE[c]	Compression perpendicular (radial)	Compression parallel	Tension parallel	Shear parallel	Hardness
						Brown-rot					
Softwoods											
1	57	20–38	—	—	—	—	—	—	—	2	—
2	—	20–50	5	27	13–50	4–55	18–24	10	23–40	—	—
4	75	25–55	—	—	—	—	25–35	—	—	6	7
6	—	62–72	16	—	61	66	48	25	60	—	—
8	—	78	—	—	—	—	48–60	—	50	15	21
10	—	85	36	—	70	—	66	45	—	20	—
Hardwoods											
1	—	6–27	—	—	—	—	—	—	—	—	—
2	36	31–50	—	54	32	—	6–10	—	56	—	—
4	—	60–70	—	69	49	—	—	—	—	—	—
6	—	80	—	75	61	—	16–25	—	—	—	—
8	—	9–89	13–34	—	—	—	19	—	82	—	—
10	60	70–92	—	—	—	—	—	—	—	—	—
						White-rot					
Softwoods											
1	55	—	—	—	—	—	—	—	—	—	—
2	—	—	—	—	—	—	10–20	—	4–38	—	—
4	—	—	—	—	—	—	—	—	8–43	—	—
6	75	—	—	—	—	—	32–61	—	10–49	—	—
8	—	—	—	—	—	—	—	—	14–58	—	—
10	85	—	—	—	—	—	—	—	20–63	—	—
Hardwoods											
1	—	21	—	—	—	—	4	—	—	—	—
2	—	26	—	28–35	13–14	4	5	—	22–42	—	—
4	70	44	—	38	20	—	—	—	17–44	—	—
6	75	50	—	45–53	20–27	10	12–27	14	12–58	—	18
8	—	—	—	—	—	—	—	—	14–49	—	—
10	85	60	—	58	24	14	35	20	20–50	—	25

[a]From Wilcox (1978). Values obtained from published experimental results and adjusted to equivalent weight loss levels.
[b]Sources: Brown (1963), Cartwright and others (1931), Gillwald and Michalak (1963), Hartley (1958), Henningsson (1967), Kennedy (1958), Kennedy and Ifju (1962), Kubiak and Kerner (1963), Mizumoto (1966), Mulholland (1954), Pechmann and Schaile (1950), Richards (1954), Scheffer (1936), Toole (1971), and Wilcox (1968).
[c]MOR, modulus of rupture; MOE, modulus of elasticity.

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