Tolerable Moisture Content of Materials

Is a Criteria Needed for ASHRAE 160?

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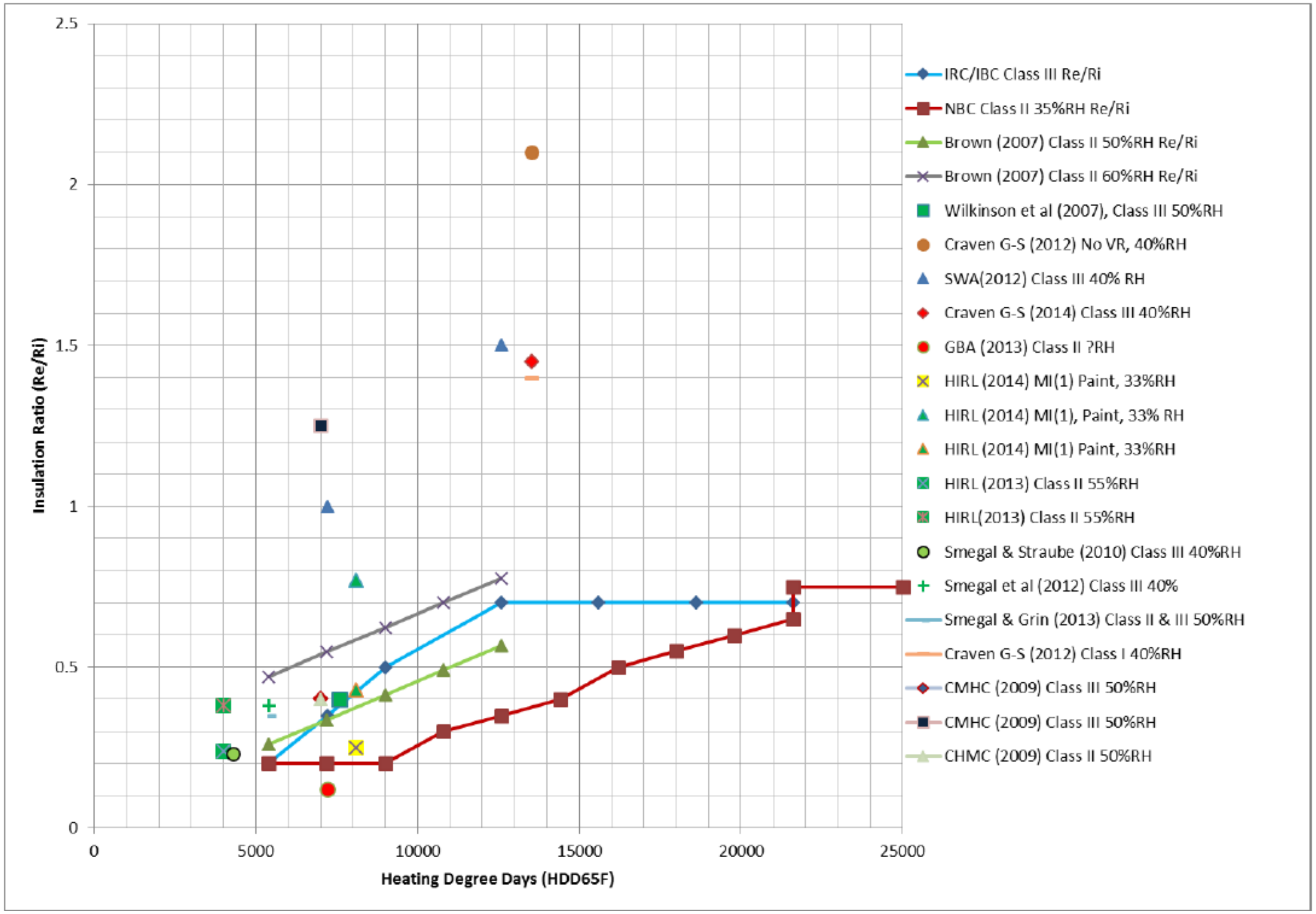
Current ASHRAE 160 Provisions

- 4.1 – Initial moisture content = EMC80 (equilibrium Moisture content at 80%RH)
- Pass/Fail Criteria:
  - 6.1 – Mold index ≤ 3.0 (onset of visual mold growth)
  - 6.2 – corrosion (30-day avg. surface humidity of metal < 80% RH)
- No material moisture content limit in relation to tolerance to moisture cycling
  - Structural property impacts (bending strength, fastener withdrawal/shear, edge tear-out, etc.)
  - Serviceability impacts (shrink/swell, expansion/contraction, buckling, spalling, freeze-thaw…)

Important Qualifier!

- None of the data presented herein should be taken as a statement (good or bad) about OSB or any other material's moisture tolerance.
  - OSB is the primary wall and roof sheathing in the market today
  - Therefore there is sufficient laboratory and field data available to assess OSB performance
  - Any material used inappropriately will cause problems.
- Neither is it meant to make a statement that one means of controlling moisture cycling in a wall assembly is better or worse than another.
  - Any method done wrong will cause problems.
- This is a review of data on OSB performance (laboratory and field)
  - Experience with OSB provides a reasonable basis for understanding the moisture tolerance of materials as it relates to in-service conditions for exterior wall sheathings

Data on Walls with Exterior Insulation



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Data on Walls with Exterior Insulation

- ABTG RR No. 1410-03
- Appropriate insulation ratio (IR) can protect moisture sensitive materials from high moisture cycling (the reverse also is seen when IR is too low for the design conditions).
- IR is defined here as the ratio of exterior continuous insulation to cavity insulation (Re/Ri).
- As the IR increases, materials to the interior of the exterior insulation experience less moisture and temperature cycling.

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Data on Walls with Exterior Insulation

- Concept used in since 1995 in National Building Code of Canada (NBC) with Class I/II interior vapor retarders (VR) where low-perm (< 1 perm) exterior materials are present.
- NBC exempts all WSPs.
- Same principle used in IRC/IBC for Class III VR with exterior insulation.

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Data on Walls without Exterior Insulation

- HIRL (2013)* – test hut
  - Climate Zone (CZ) 4
  - Mild winters (lower than average)
  - RH=55% per ASHRAE 160
- Walls with Class III VR (paint) on Interior
  - 34 perm(dry cup);
  - 7/16” OSB - 1.4perm(Wet Cup) and vented siding with high-perm WRB wrap on exterior
  - OSB MC = 23-25% over most of winter and into spring
- Walls similar to above, but with Class II VR
  - OSB MC < 20%
- Comparative: Walls similar to above, but with Class II VR and exterior CI
  - OSB MC < 15%

*HIRL (2013). Characterization of the Moisture Performance of Energy-Efficient and Conventional Light-Frame Wood Wall Systems, prepared for USDA/FPL (Joint Venture Agreement 12-JV-11111136-070) by Home Innovation Research Labs, Inc., Upper Marlboro, MD. November 2013.

Data on Walls without Exterior Insulation

- OSB in walls with Class III VR (MC = 23-25%) experienced 19% differential loss of structural bending capacity over two winter cycles relative to OSB samples from walls with Class II VR (MC<20%).
  - Reference is OSB in wall with Class II VR (which was also exposed to some level of MC cycling
  - Thus, actual strength loss (relative to unexposed, dry OSB) was probably greater.
  - Bending capacity is a proxy for other structural properties (USDA/FPL wood handbook)
- All of the above walls are considered code-compliant (even though performance is very different)

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More Data

- Lstiburek, Ueno, Musunura (2015)* – Actual home in CZ 5;
  - 12” double stud walls in with open-cell spray foam (OCSPF) or cellulose cavity insulation;
  - Class III VR on interior;
  - Vented (vinyl) siding with high-perm wrap on exterior;
  - Multiple winters (one severe);
  - One with ventilation problems;
  - Indoor RH 10-20%, 30-50%, 20-30% for each of 3 winters.
- BSC only monitored these walls (UENO, 2015); they did not design them
- OSB peak wintertime moisture content for the cellulose wall ranged from 15-23% in mild winter to 25%-33% in worst winter condition;
  - OSB MC in the OCSPF wall was generally better, but did reach 26% in the worst winter condition with high indoor RH.

* Lstiburek, J., Ueno, K., and Musunura, S. (2015). Modeling Enclosure Design in Above Grade Walls, Building America Program, Building Technologies Office, U.S. Department of Energy, Washington, DC.

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More Data

- Walls were disassembled:
  - “no signs of moisture damage or mold were visible”
  - “grain raise” was reported for the OSB on the cellulose insulated wall (Cellulose is more vapor permeable than OCSPF)
  - Corrosion of fasteners was also noted
- Grain raise on surface is indicative of exposure to high moisture levels.
  - Visual (surface) observations don’t necessarily indicate what happened to intrinsic structural properties.
- Measured hourly OSB surface RH/T data indicated a mold index (MI) of marginally below 3 for the wall with cellulose insulation (MI=2 for the OCSPF wall)
  - WUFI modeling predicts MI ~2.5 for the cellulose wall
  - Mold index of 3 represents onset of visual mold growth

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More Data

- This wall fails by the older mold criteria (too conservative for evaluation of mold risk), but passes by the new mold criteria.
- Even though this wall passes by the new mold criteria, OSB structural property degradation has likely occurred (and may be progressing) due to high moisture content cycling.
- UENO (2015)** recommended use of a Class II VR for the cellulose wall instead of the Class III VR as used.
  - Was the observed OSB condition and mold index performance considered to be marginal or unacceptable for the cellulose wall with class III interior VR?
- This data also indicates a need for a moisture content tolerance criteria to complement the improved mold criteria in ASHRAE 160

**Ueno, K. (2015). Monitoring of Double-Stud Wall Moisture Conditions in the Northeast. Building America Program, U.S. Department of Energy, Washington, DC. (NREL Contract No. DE-AC36-08G028308)

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More Data

- Six identical occupied homes in CZ5/6 (border);
  - 2x6 R19 walls (kraft-faced batts) Class II interior VR with 7/16" OSB and high-perm wrap and vented (vinyl) siding on exterior (Dow 2013; Dow 2014; Buildings XIII)
- These are all code-compliant walls
- Indoor RH during winter: between 25% to 35% for all homes (occupant variation)
- OSB moisture content for most homes cycled above 20% and, for several homes, above 25%.

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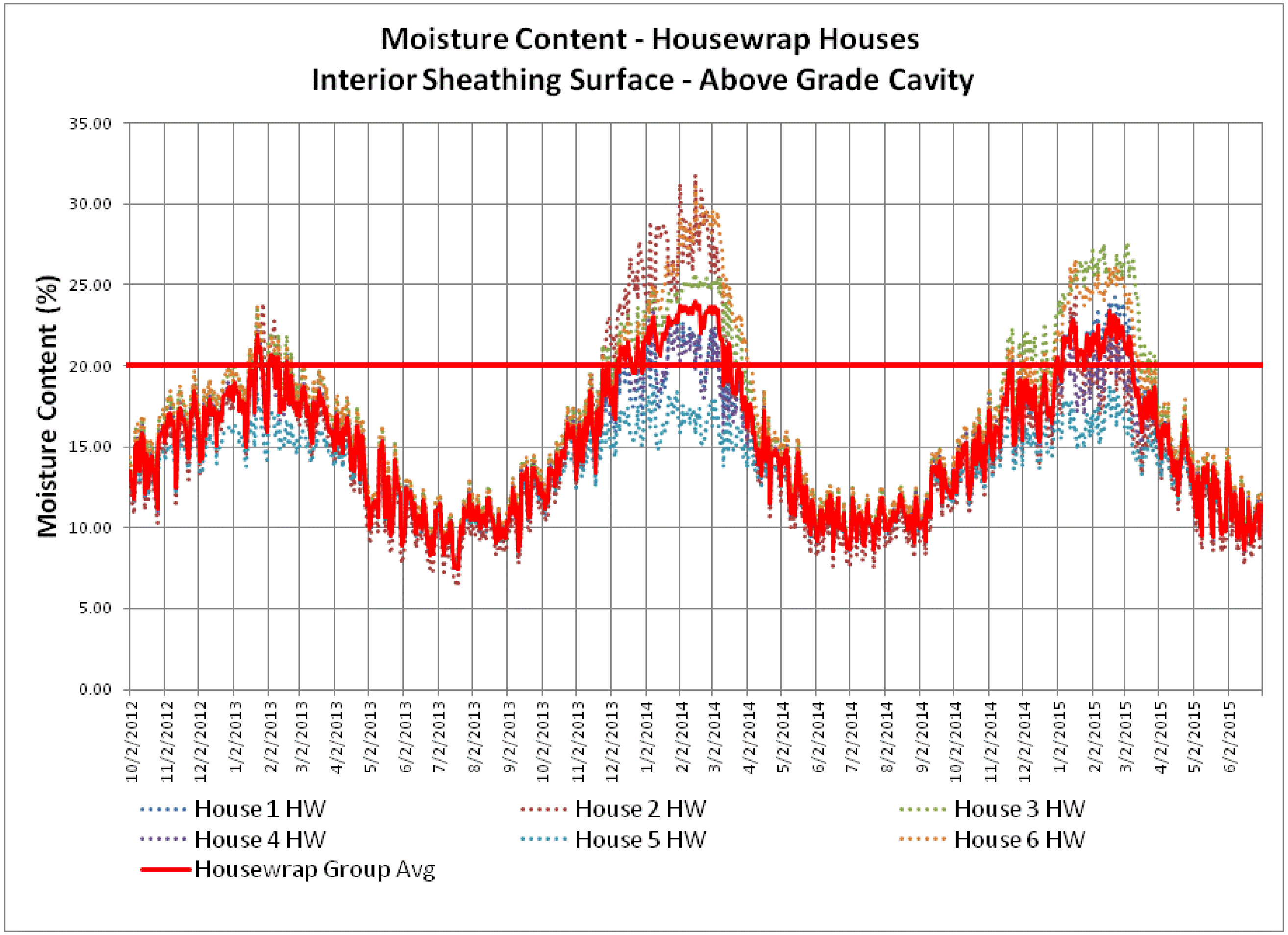
More Data



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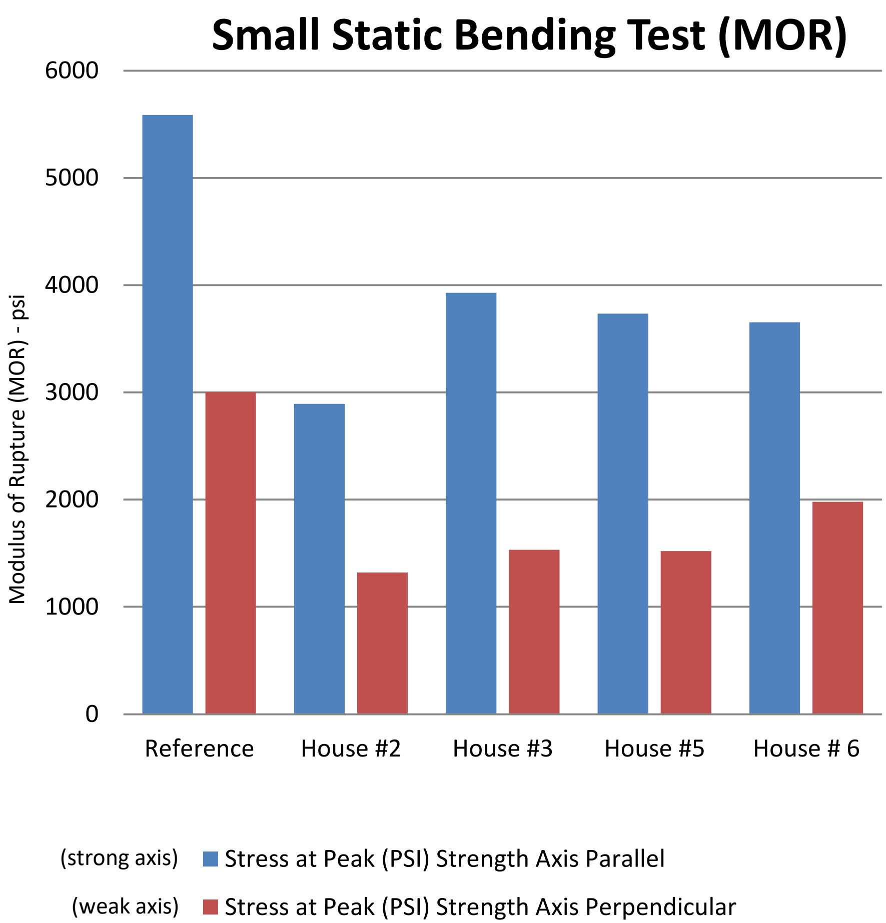
More Data

- OSB samples removed after 3 winters and tested per DOC/PS2 Section 7.6 showing estimated strength loss of 30% to 45% in the strong and weak axis of the panel.
  - Reference is a new OSB panel purchased at time of sampling (not from original construction);
  - But, it aligns with data for Aspen/mixed hardwood OSB, MOR = 4200 to 5600 psi (USDA/FPL, Wood Handbook, Table 12-3)



Above data not included in Dow's Building XIII Paper

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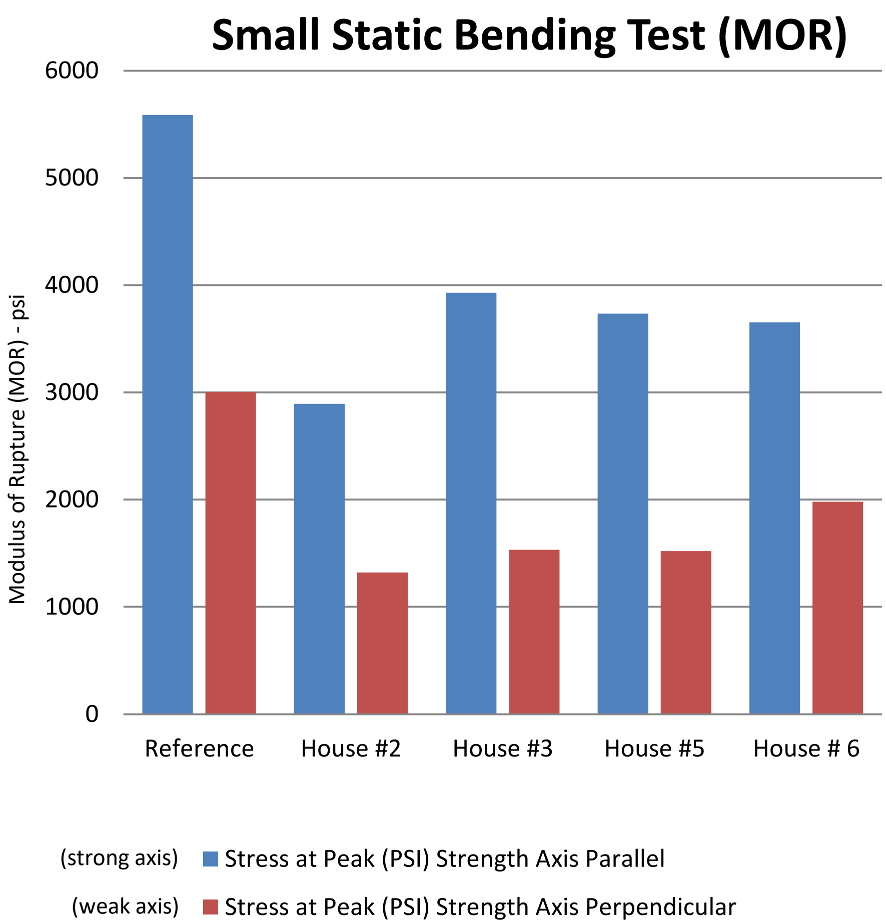
More Data

- Loss of MOR is consistent with HIRL (2013) data reported earlier (although worse here due to more winter cycles and some with higher OSB MC)
- Result is also consistent with USDA/FPL study correlating MOR loss with laboratory accelerated moisture tests vs. actual exposures (addressed later)
- Is a Class II (kraft) Interior vapor retarder adequate for these conventional walls in CZ 6 or northern extreme of CZ 5?
  - Two similar homes in CZ5 (HIRL 2014) with 2x6 R23 walls experienced OSB mc <15% with use of a 4-mil poly (Class I) interior VR.



Above data not included in Dow's Building XIII Paper

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More Data

- Need to define material moisture tolerance in a manner relevant to “in-wall” (in-situ) cyclic moisture content exposure and the method of material structural design property qualification
- Effects of moisture cycling on material strength properties?
  - Gypsum wallboard/sheathing
  - OSB
  - Plywood
  - Other sheathing materials?
- Methodology should be generally applicable

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Material standard for OSB

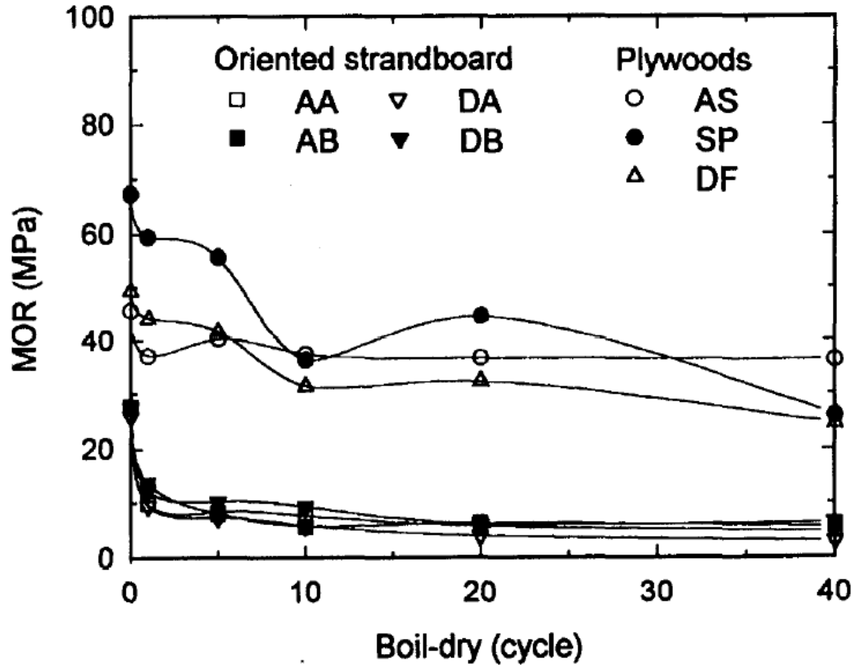
- DOC/PS2 – vacuum pressure soak/dry test
  - One wetting cycle required for OSB qualification using small sample bending test
  - Two criteria options for 7/16"OSB:
    - (a) MOR > 2470 psi (17 MPa) or
    - (b) no greater than 50% strength loss on average (with allowance for no greater than 60% strength loss for individual panels)
- This test method could provide a useful means of benchmarking "tolerance" of materials (not just OSB)??

Material standard for OSB

- Is there a need to specify different performance/exposure levels for OSB used in walls that are designed for a mold index of 3 without a separate limit for maximum moisture levels (e.g., Exterior vs. Exposure 1 rating)?
  - Is a wet service factor needed to adjust structural properties (as done for solid wood materials) when used in a wall design without controlling max moisture content?
- How does PS2 single wetting cycle (vacuum soak) and performance qualification correspond (or not) to wetting cycles and strength degradation that may occur in actual walls after initial construction exposure?

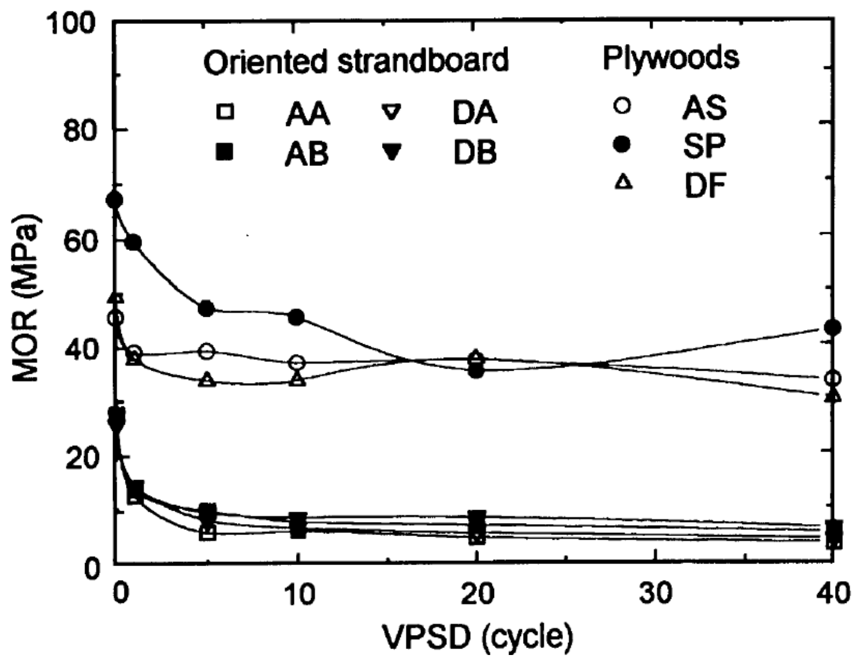
WSP Moisture Cycling vs MOR Study

- Okkonen, E. and River, B.H., "Outdoor Aging of Wood-Based Panels And Correlation With Laboratory Aging," Forest Products Journal, Vol.46, No.3, Madison, WI, March 1996. USDA/FPL www.fpl.fs.fed.us/documnts/pdf1996/okkon96a.pdf
  - Study to correlate laboratory tests to actual outdoor exposure
  - Boil-dry (BD) and vacuum pressure soak/dry(VPSD) accelerated aging tests used



WSP Moisture Cycling vs MOR Study

- OSB: ~50% loss of MOR in one or two cycles; plywood: ~20% loss of MOR in 2 cycles
- MOR tends to stabilize within 10-cycles – see graphs
- Comparative outdoor exposure for 1-year (Madison, WI): OSB lost 50% of MOR; Plywood, 20% loss.
- NOTE: This impact may be roughly equivalent to 4- to 5-years of cyclic winter diffusion wetting exposure of OSB in a code-compliant 2x6 wall with R19 (FG batt w/kraft facer) and high perm WRB wrap in CZ 5/6 (see data on previous slides)



APA D510 Panel design Specification

4.5.2. Service moisture conditions

Design capacities apply to panels under moisture conditions that are continuously dry in service; that is, where equilibrium moisture content is less than 16 percent. Adjustment factors for conditions where the panel moisture content in service is expected to be 16 percent or greater are shown in Table 7.

- If OSB > 16% MC in walls, then strength reductions are required for multiple design properties
- What if MC cycles above 20% annually? What about 25%?
- In practice, application of OSB in walls is generally assumed to be in a “dry” condition (below 16% MC).

TABLE 7

MOISTURE CONTENT ADJUSTMENT FACTORS FOR WOOD STRUCTURAL PANELS

Capacity	Moisture Content Adjustment Factor (C_M)
Strength (F_bS, F_tA, F_cA, $F_s[Ib/Q]$, F_vt_v)	0.75
Stiffness (EI, EA, G_vt_v)	0.85
Bearing ($F_{c\perp}A$)	
Plywood	0.50
OSB	0.20
Nail withdrawal strength	0.75
Wood screw withdrawal strength and lateral strength for dowel-type fasteners (nails, screws and bolts) of 1/4 inch or less in diameter	NDS Table 10.3.3

Hypothetical Criteria

- Hypothetical criteria using vacuum pressure soak & dry test:
  - High Tolerance
    - →10 cycles w/ max 20% loss of strength
    - →25% max allowable moisture content
  - Moderate
    - →10 cycles w/ max 35% loss
    - →20% max allowable moisture content
  - Low Tolerance
    - →10 cycles w/ 50% or greater loss
    - →15% max allowable moisture content

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Hypothetical Criteria

- Based on modeling for 10th percentile design years (if based on an “average year” the max MC should be reduced)
- This criteria is intended to be used in conjunction with a separate design check using current (improved) mold criteria in ASHRAE 160.

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Caveats

- OSB qualification per DOC/PS2 may implicitly allow for some amount of strength loss in end use (or at least ensure some resistance to it for temporary construction exposure conditions only).
- But, structural design properties ARE still based on "dry" (unaged) values unless a strength reduction adjustment is used for >16%MC use conditions per APA D510, Section 4.5.2
  - Not commonly done as use inside a wall is usually assumed to be "dry".

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Caveats

- The previous data seems to indicate OSB strength loss due to moisture cycling eventually stabilizes (levels-off) AT ~40% of the original dry/new value
  - Assuming there is no persistent biological activity (decay) going on which the mold index criteria would tend to prevent.

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Caveats

- Thus, depending on how a given material's strength property is qualified for structural performance and how its degradation stabilizes under cyclic moisture aging, the above hypothetical criteria would need to be adjusted to properly assess a maximum moisture content for in-service moisture modeling
  - Avoid double-counting the impact of moisture cycle aging effects on standardized structural properties.
  - Also needs to be coordinated with "wet service factor" adjustments of strength properties if "non-dry" conditions are allowed (or not controlled).

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Caveats

- Other things to consider -- Structural and serviceability related:
  - Shrink/swell
  - Expansion/contraction
  - Buckling
  - Fastener withdrawal
  - Shear wall resistance impact
  - Others?

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What Next?

- Need a thorough literature review and research request (RTAR) for potential ASHRAE funding
  - What research is on-going on this topic?
    - DOE/BA is funding related research
- Questions/discussion?
  - NOTES from ASHRAE 160 committee meeting:
    - Recommends development of a draft RTAR (task group identified)
    - Additional literature should be reviewed to expand/refine data provided in this presentation