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Wetting and Drying Performance of Wood-based Assemblies related to on-site Moisture Management

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Advanced Building Systems

On-site Moisture Management?

- Identify potential moisture-related issues during the construction phase
  - A building isn't protected against weather until the envelope is fully protected
- Provide appropriate measures to mitigate the moisture risk

On-site Moisture Management

- “Standard” wood-frame construction in N.A.
  - Open and exposed construction
- Basic protection is commonly seen
  - Wood products wrapped for shipping or coated with water repellent
  - Covering with tarp is quite common at site
  - Prefabrication becomes increasingly common
- Emergence of using temporary roofs for protection
  - Fixed, or liftable

What is this Paper about?

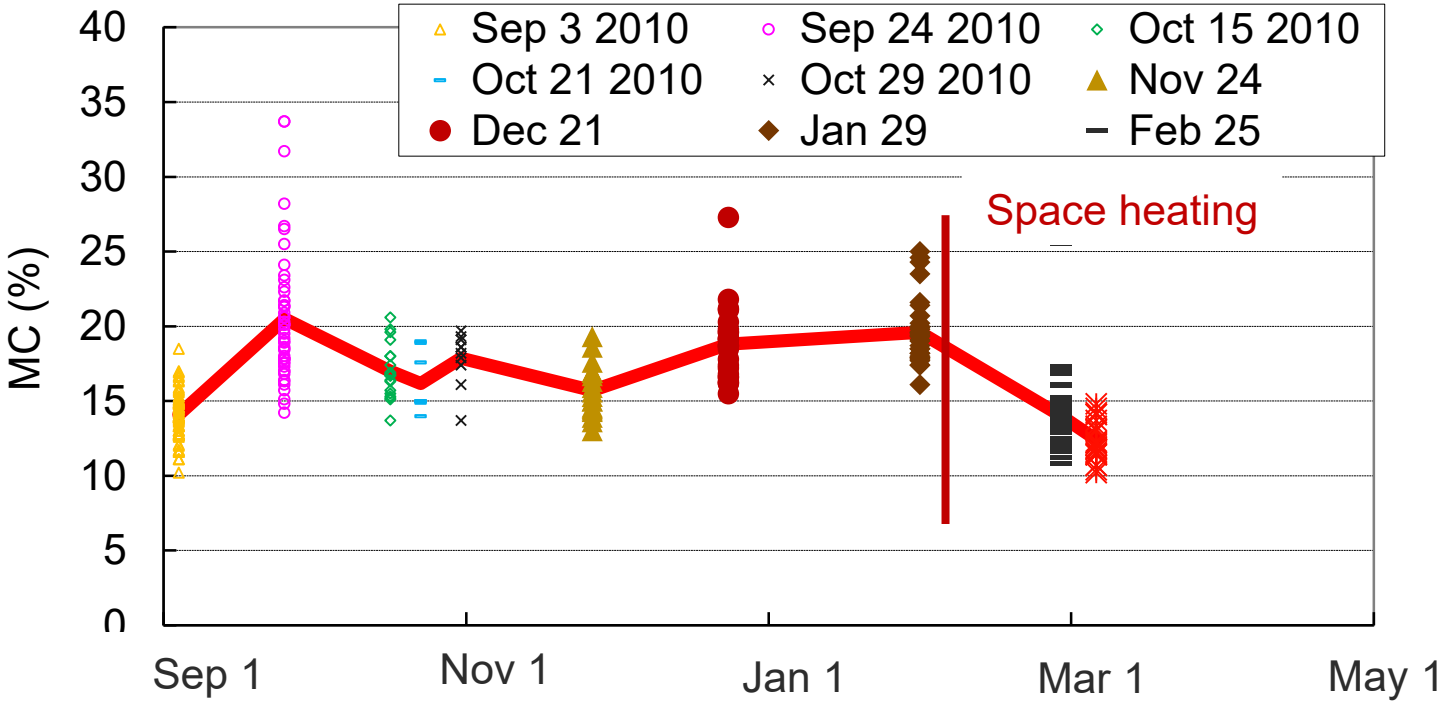
- Provide relevant basic data
  - MC in light wood-frame construction (field studies)
  - Wetting and drying of simulated roof (lab test)
  - Wetting and drying of nail-laminated timber (NLT) (lab test)
  - Wetting of cross-laminated timber (CLT) in construction of UBC Brock Commons (field study)

Wood MC in Wood-Frame Construction

- Measuring lumber MC in light wood-frame construction
  - MC is an important parameter for predicting vertical movement
  - MC data collected is a baseline for on-site moisture management

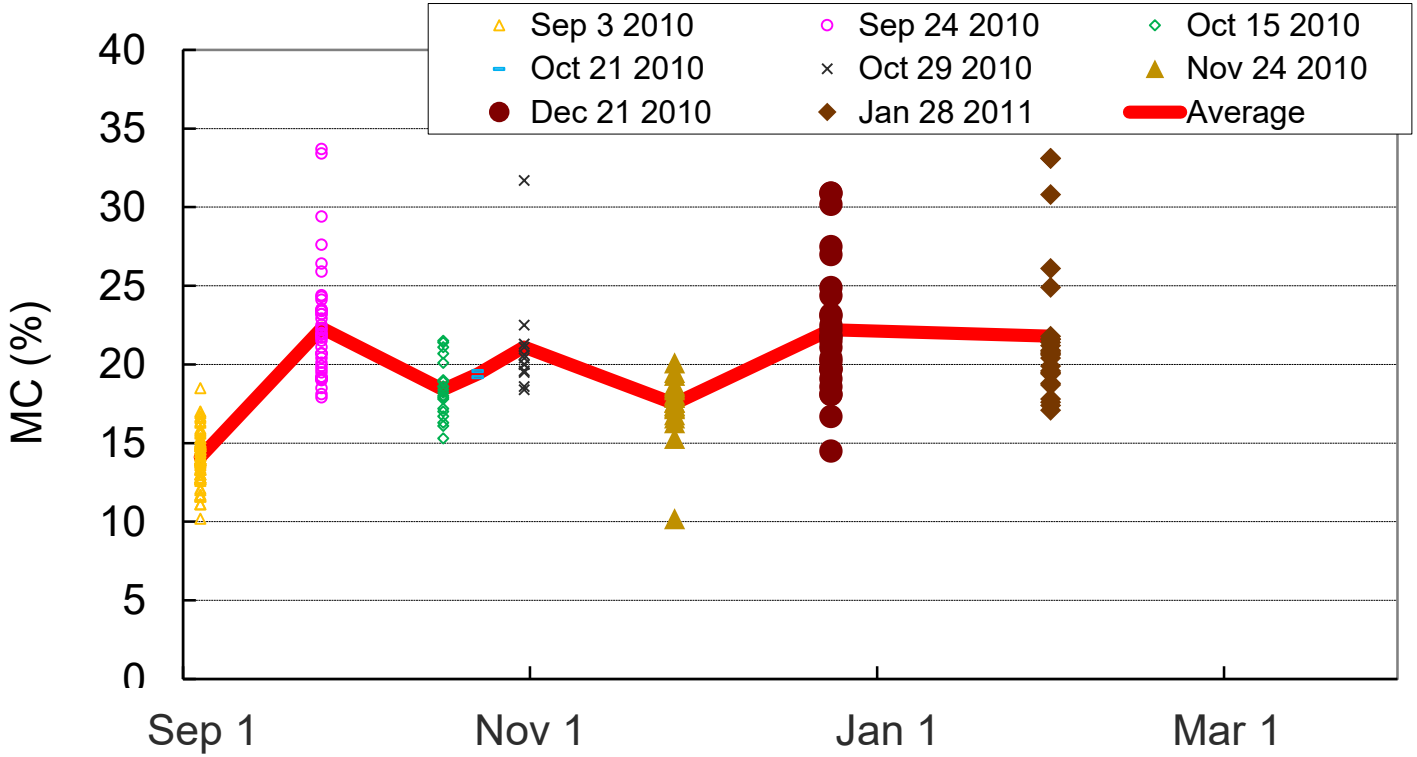
Lumber MC Change: 4-Storey Building

- Framed over the winter
- Studs on 1st floor, chest height
  - Average MC below 20% before space heating, large variation

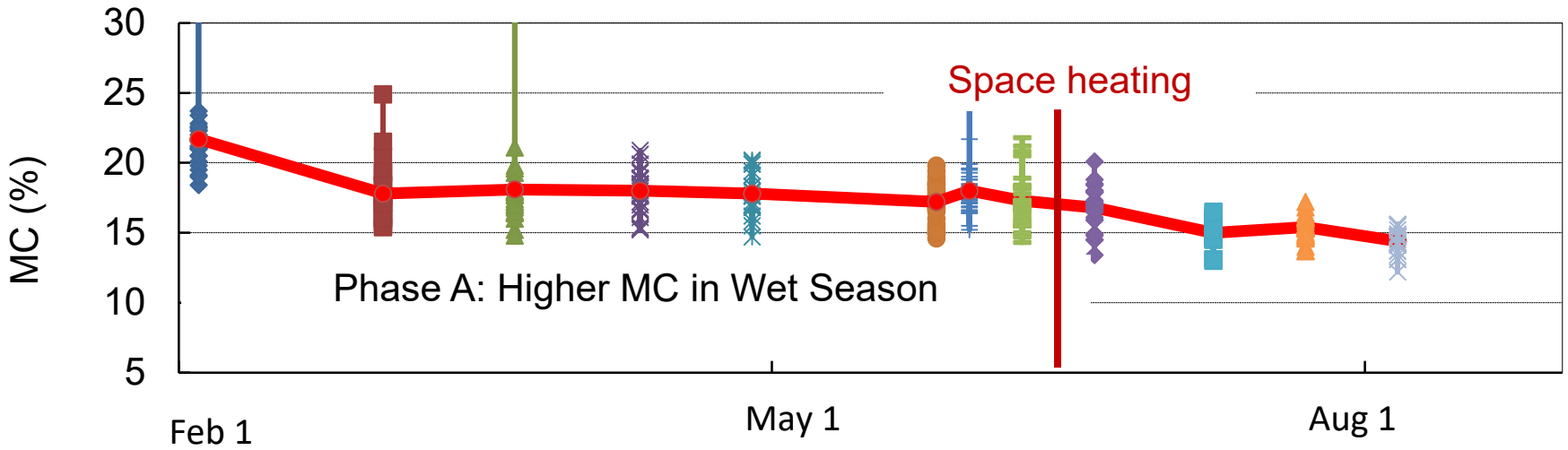


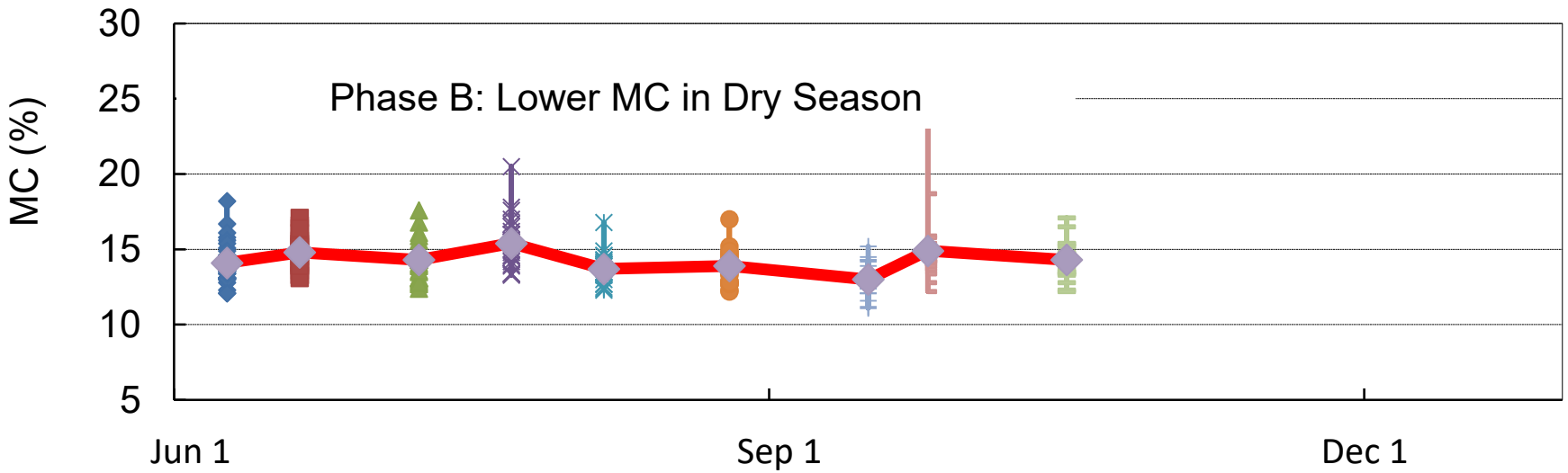
Lumber MC Change: 4-Storey Building

- Sill plates
  - Average MC higher than 20% before space heating, large variation



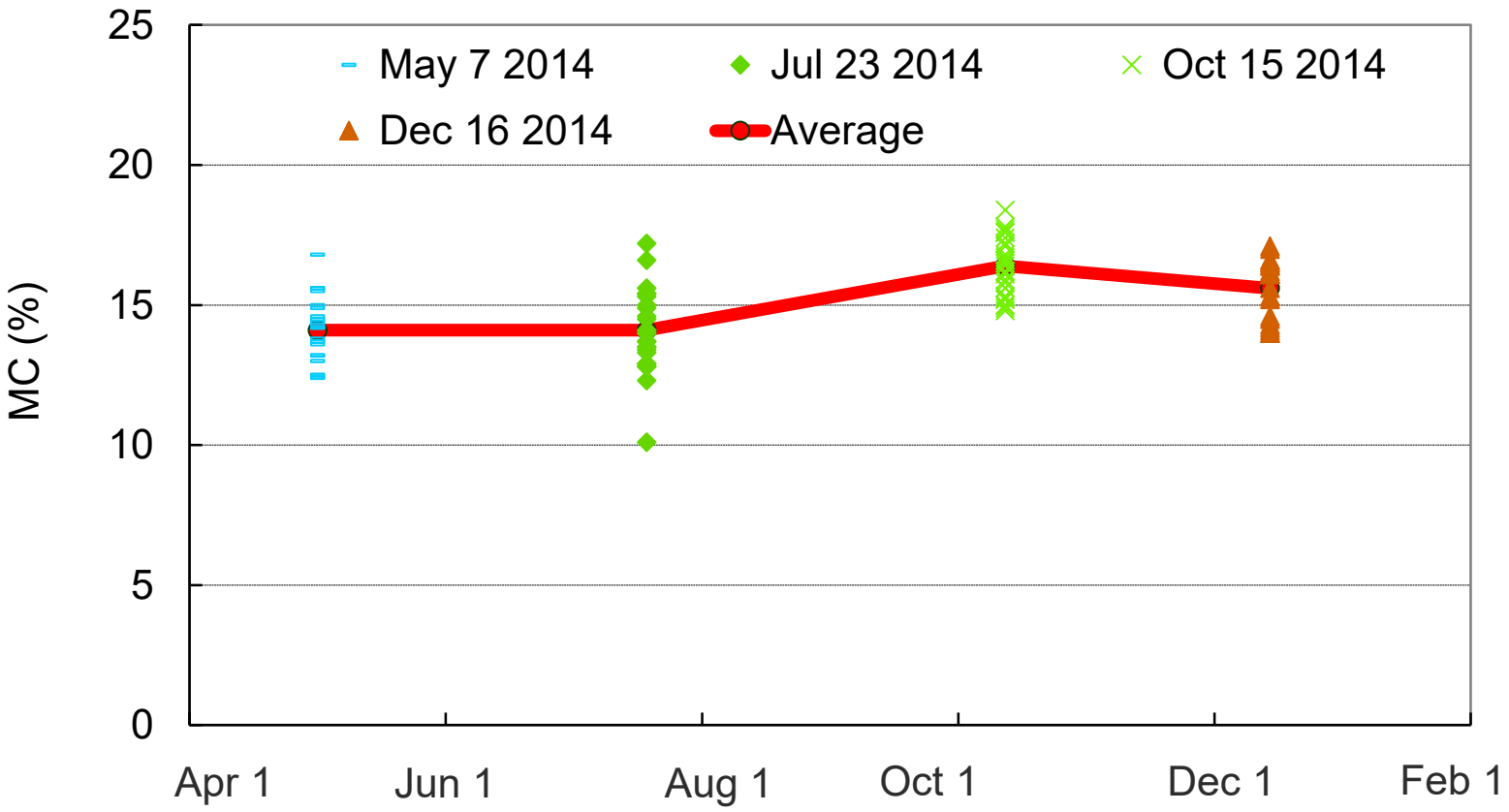
Lumber MC Change: 5-Storey Building





Changes in MC at chest height of studs, 1st floor

Lumber MC Change: 6-Storey Building



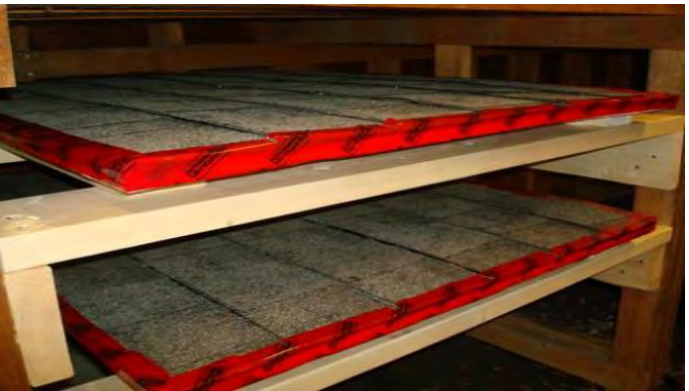
Lower MC around 15% when framed and sheltered in dry season

Lumber MC Change: Summary

- Framing in a wet season
  - 20% on average before space heating provided
  - Within a wide range
  - It is challenging to maintain MC below 19% before enclosure
  - Forced drying becomes necessary to improve construction efficiency
- Framing in a dry season
  - 15% on average
  - Within a narrow range

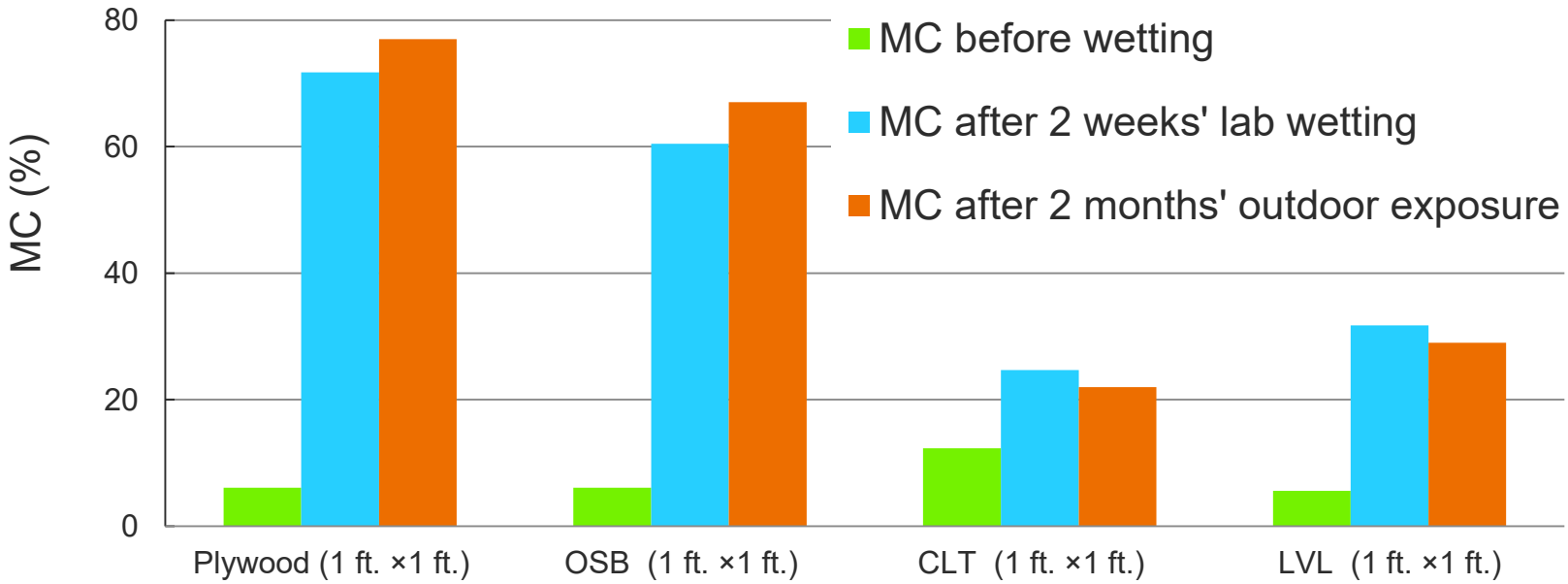
Wetting and Drying of Simulated Roof

- Plywood, OSB, LVL, or CLT as the roof panel
- Pre-wetted wood, built into different assemblies
  - Covered with impermeable membrane, or felt + asphalt shingle
  - With and without 3” closed-cell spray foam underneath
- Drying under different environmental conditions
  - In an open shed, no heating
  - Heating underneath to assess effect of temperature differential



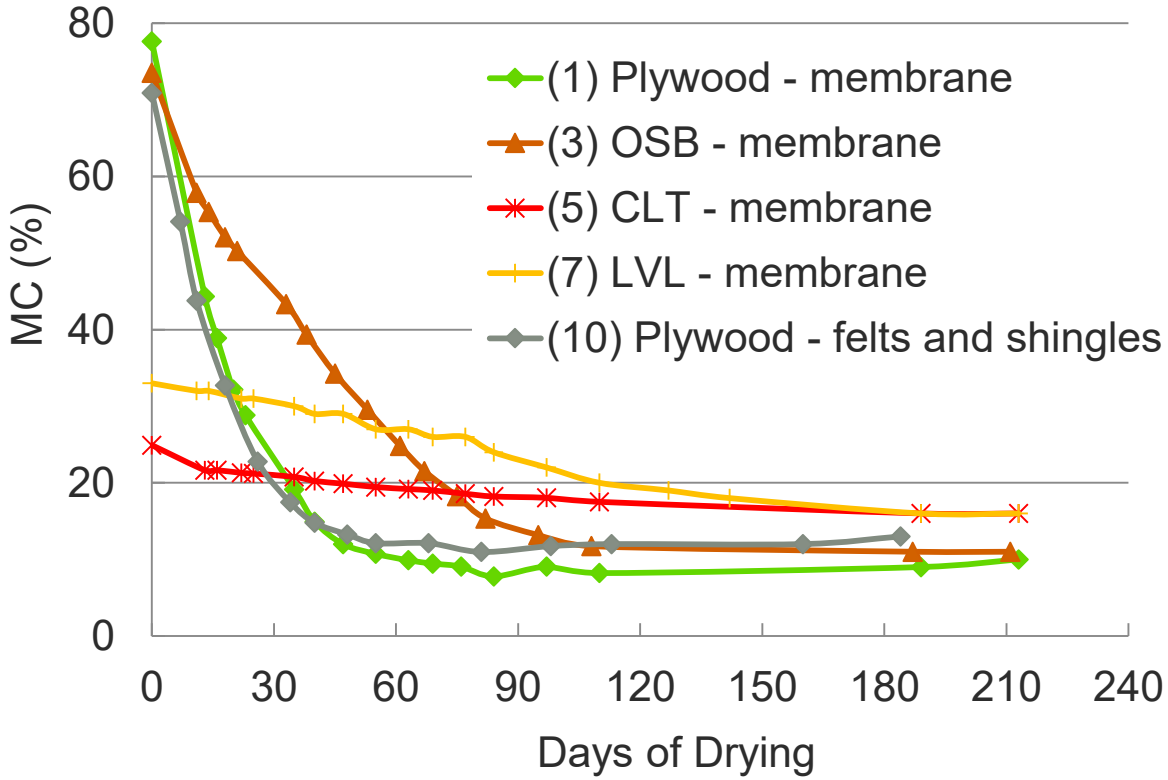
Wetting and Drying of Simulated Roof

- Materials have different wetting potential
  - Reduced water absorption from plywood, OSB, LVL, to CLT
  - CLT and LVL wet up slowly
  - Factors: wood species, end grain exposure, gap/void, glue, water repellent…

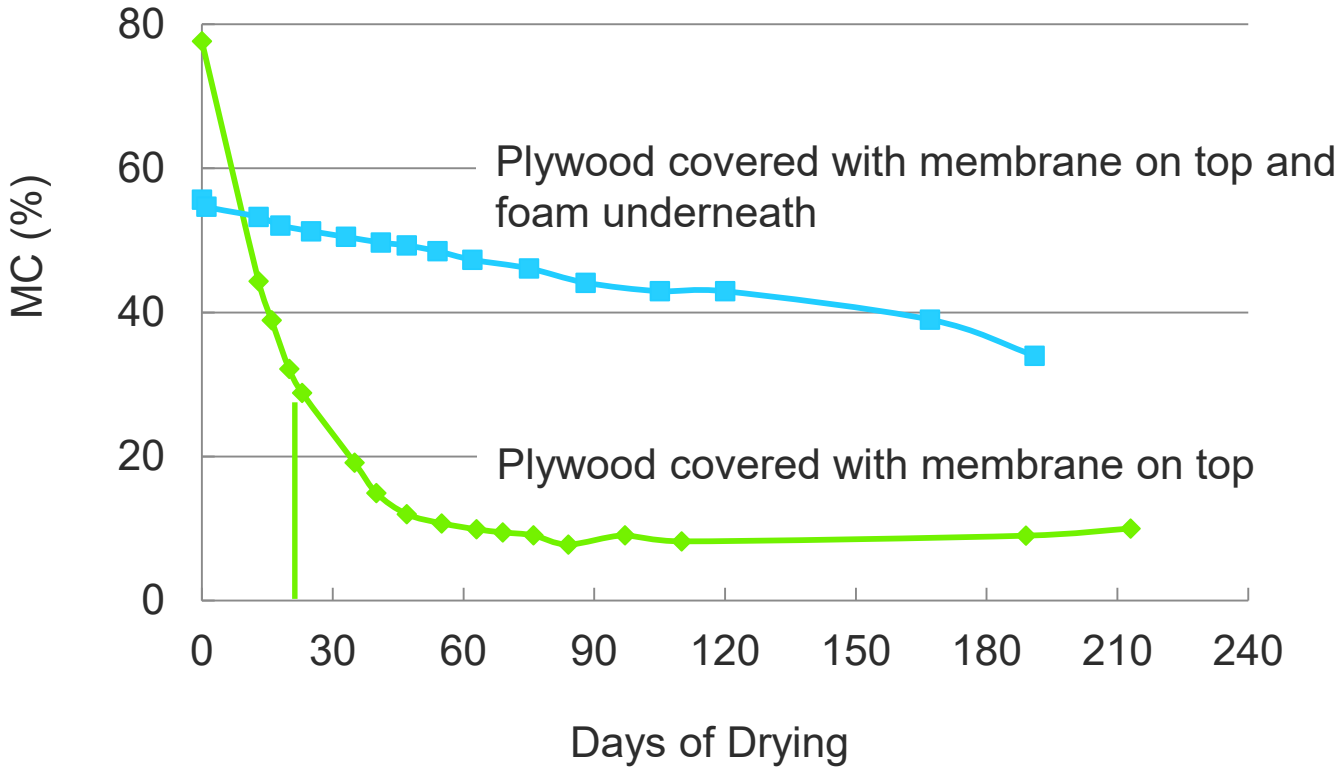


Wetting and Drying of Simulated Roof

- Factors affecting drying rates
  - Drying rates reduced from plywood, OSB, LVL, to CLT with the same impermeable membrane on top
  - Plywood with membrane and felt+shingle showed similar rates

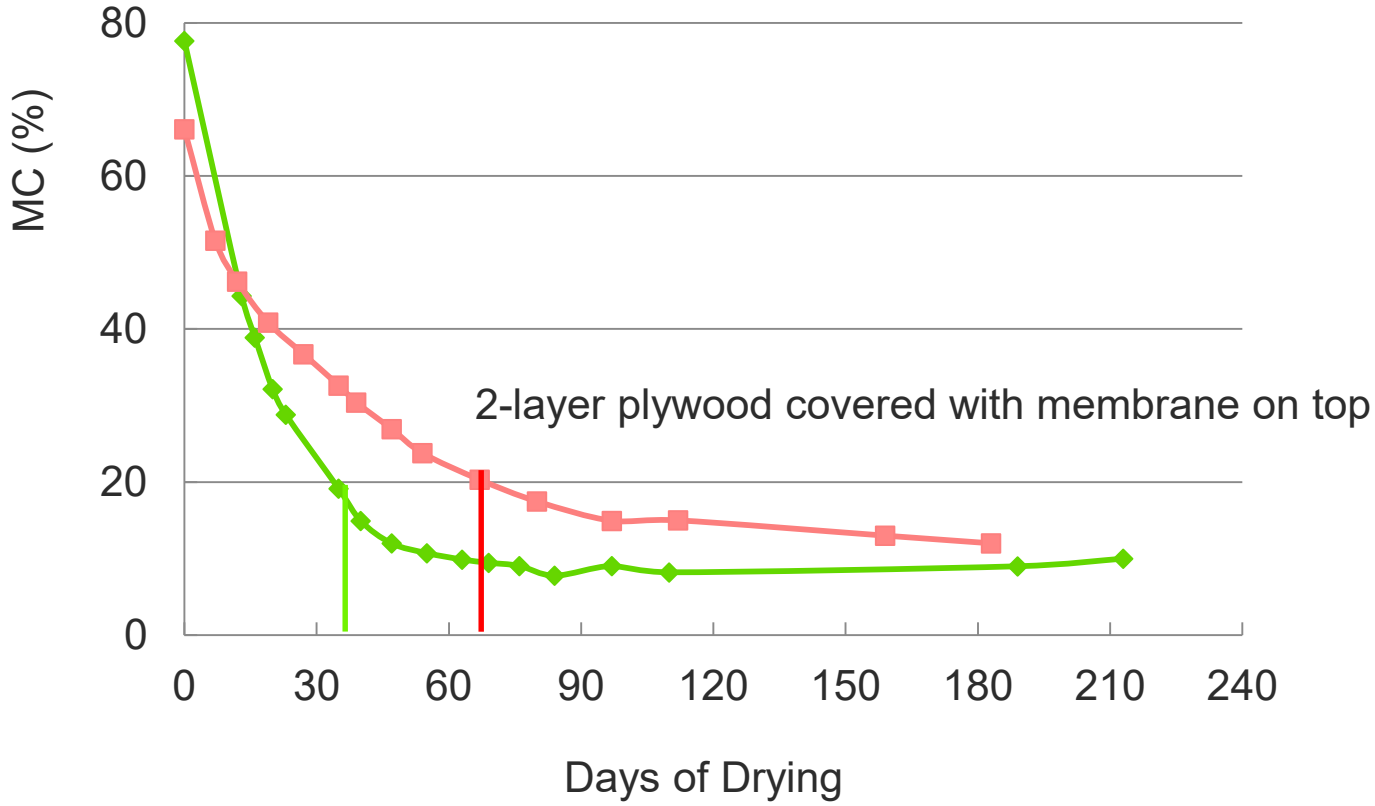


Wetting and Drying of Simulated Roof



Wet plywood, sandwiched between impermeable membrane and closed-cell spray foam, did not dry

Wetting and Drying of Simulated Roof



Double-layer plywood deck, sometimes specified for structural performance, reduced drying

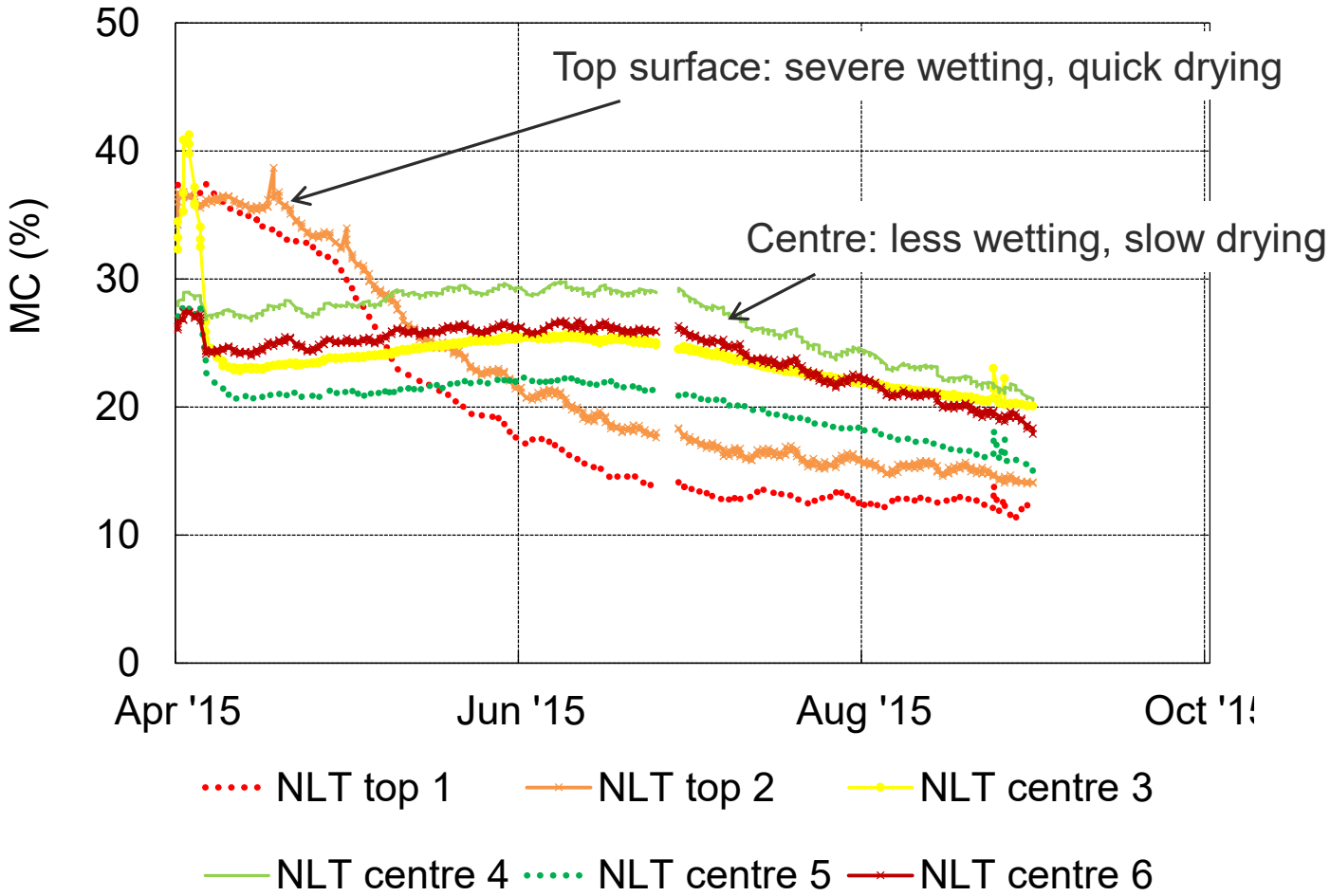
Wetting and Drying of Roof: Summary

- Drying takes a long time, once wetting occurs
  - Weeks/months required under natural drying condition
- Drying greatly affected by membrane or insulation
  - Large effect caused by closed-cell foam insulation
  - Little difference between two types of membrane
    - Felt + shingle confirmed not more permeable to allow drying
- Space heating confirmed to be effective for drying
  - Even under reversed temperature differential, for plywood

Wetting and Drying of NLT

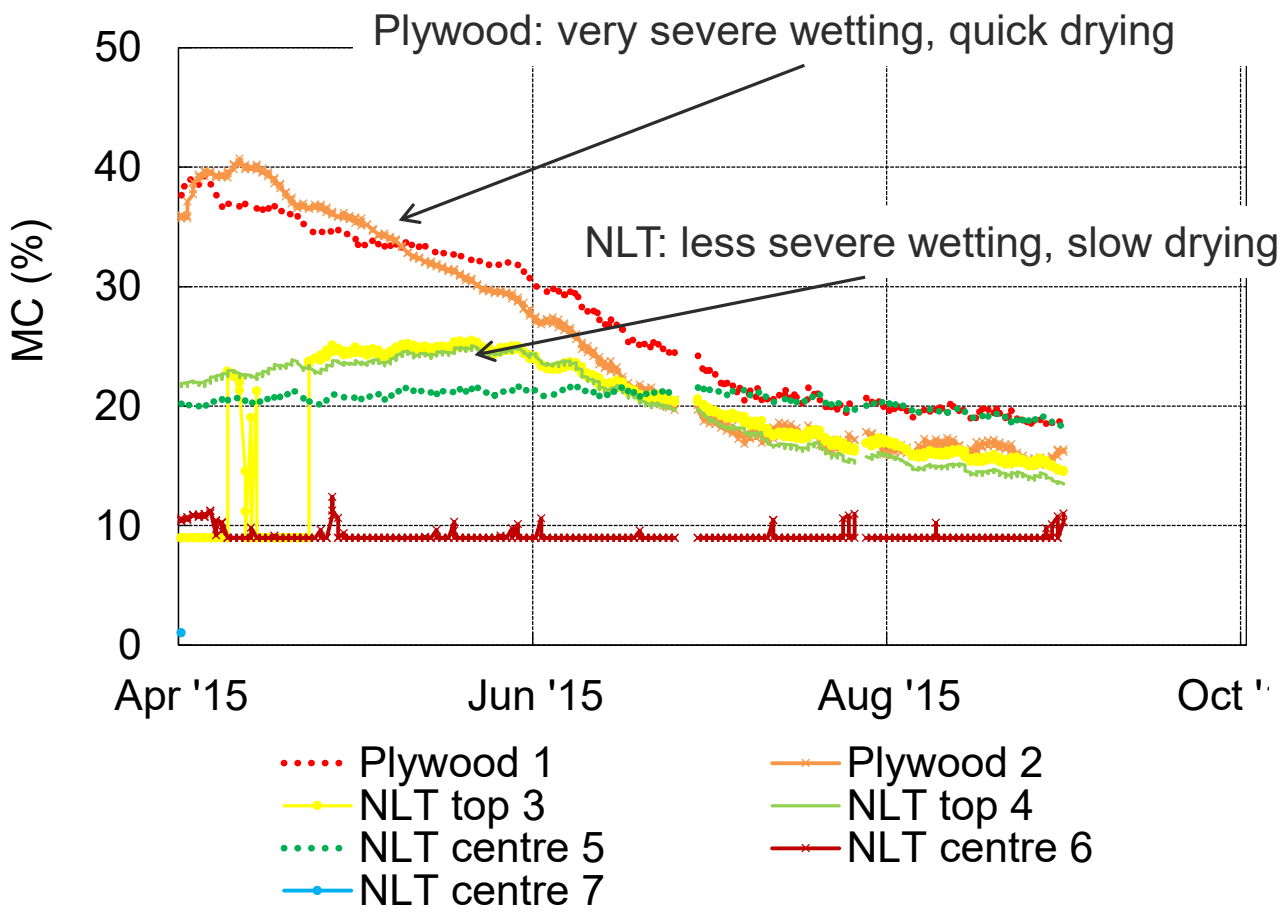
- Wetting
  - Exterior, natural exposure
  - Hourly spray of water in lab
- Drying
  - Exterior, natural exposure
  - In shed
    - With/without space heating underneath
- Potential protection method
  - Sheathing (plywood)
  - Protective membrane
    - Building paper
    - Permeable plastic sheet
    - Impermeable self-adhesive membrane

Wetting and Drying of NLT



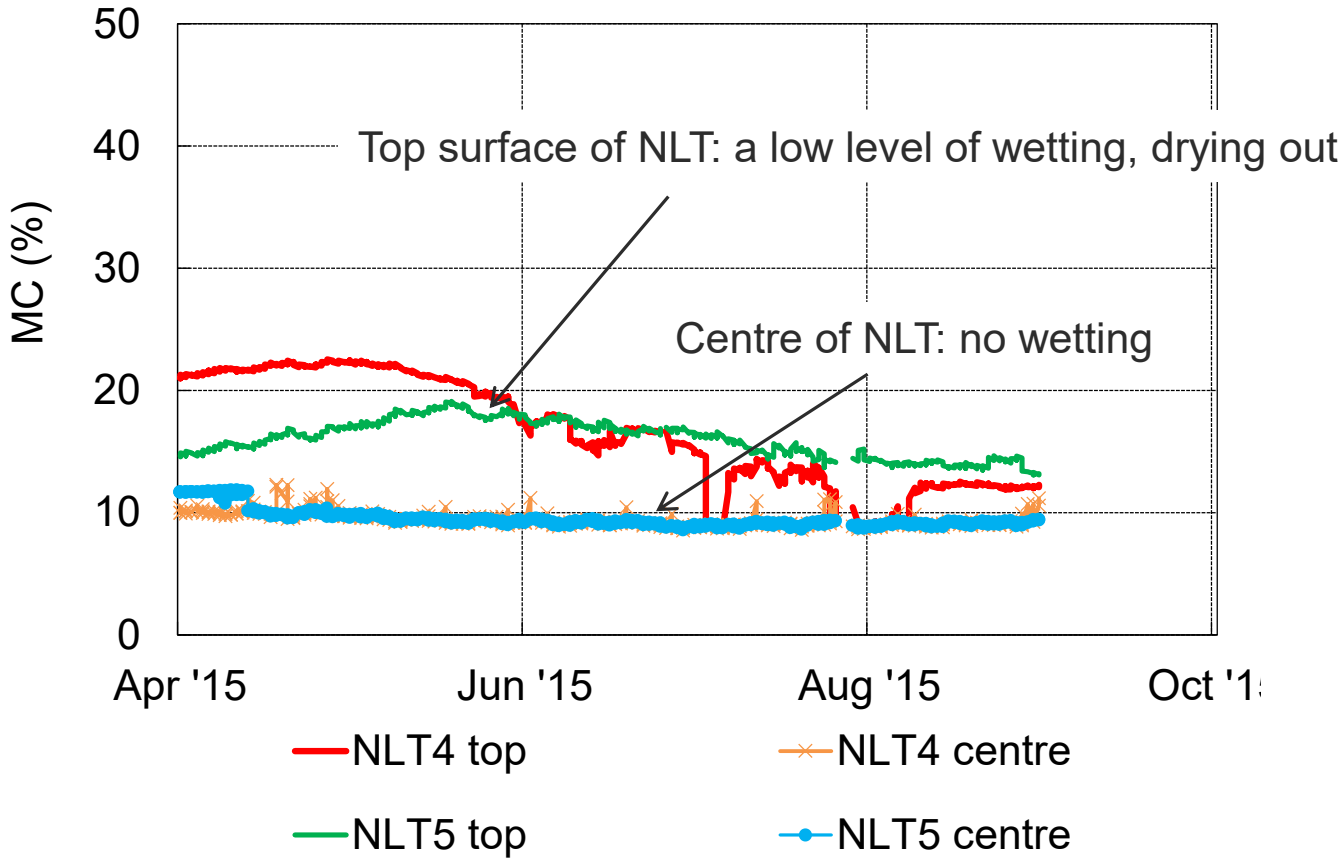
Bare NLT without sheathing or membrane on top, wetted in lab and left for drying in shed, no heating

Wetting and Drying of NLT



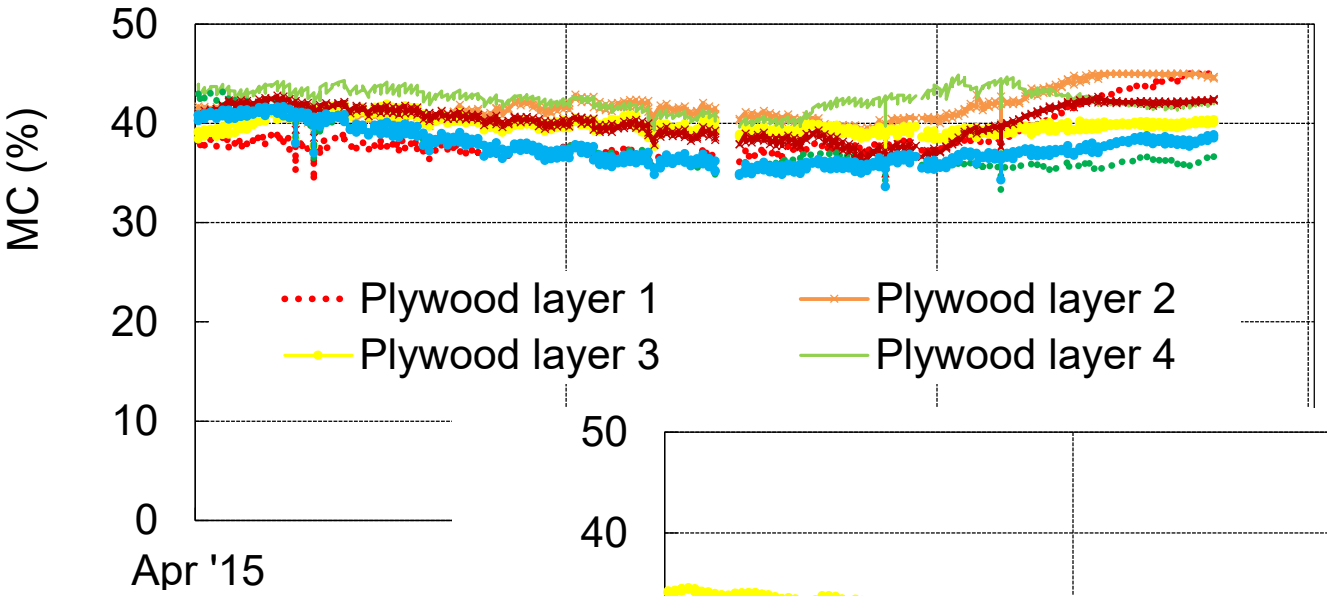
NLT covered with plywood sheathing on top, wetted in lab and left for drying in shed, no heating

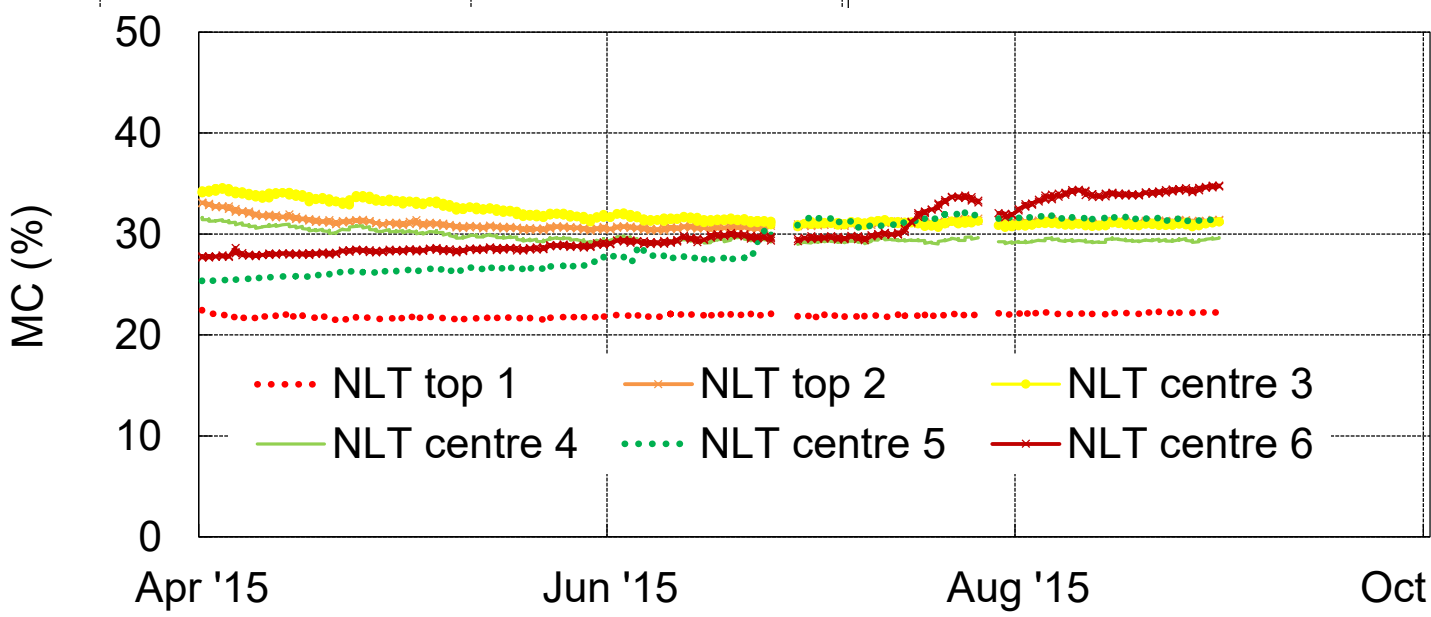
Wetting and Drying of NLT



NLT covered with plywood and building paper on top, wetted in lab and left for drying in shed, no heating

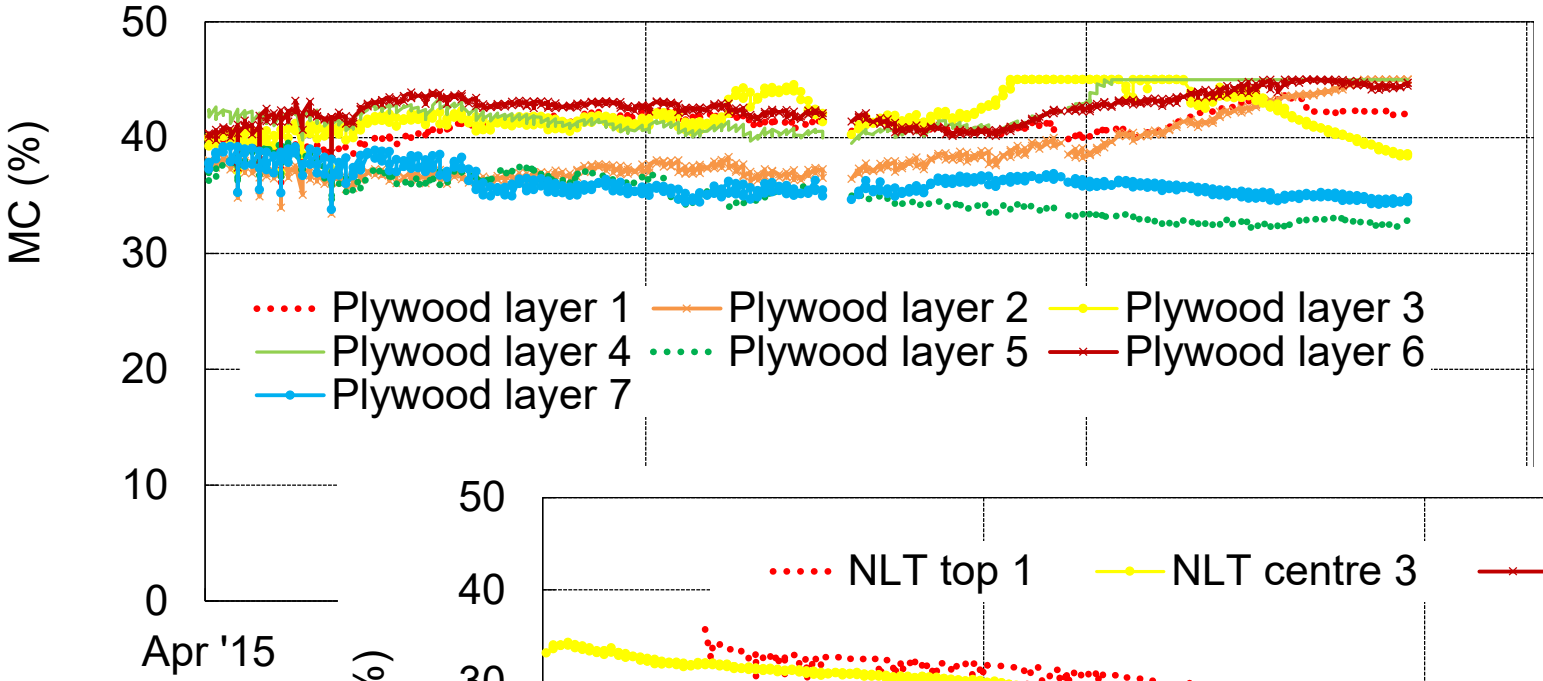
Wetting and Drying of NLT

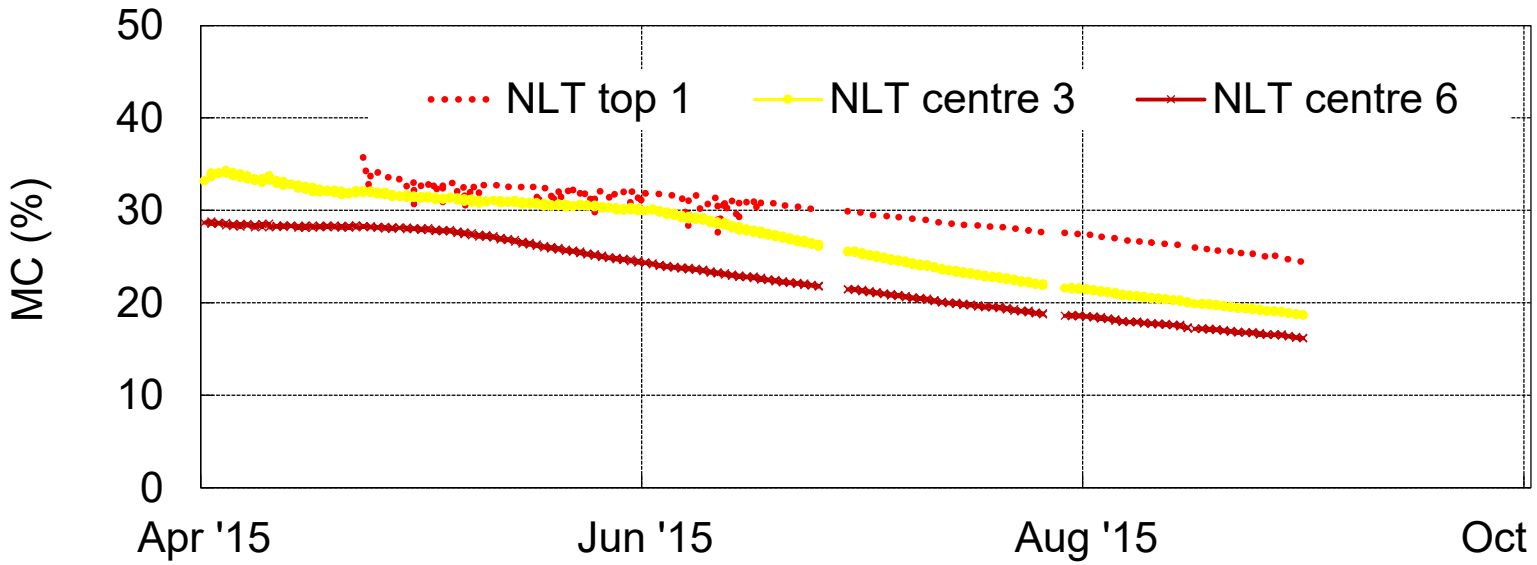




Wetted NLT and plywood, then covered with impermeable membrane on top, left for drying in shed, no heating

Wetting and Drying of NLT





Wetted NLT and plywood, then covered with membrane on top, left for drying in shed, with heating below NLT

Wetting and Drying of NLT: Summary

- Without protection, water penetrates and gets trapped in NLT easily
- Membrane and sheathing may provide some protection to NLT below, provided gaps sealed immediately upon installation
- Wet NLT should always be dried prior to further assembly or enclosure
- Heating shown to be less effective in drying NLT, i.e., large built-up members

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Wetting of CLT at Site

Comprehensive on-site protection provided in this 18-storey timber building

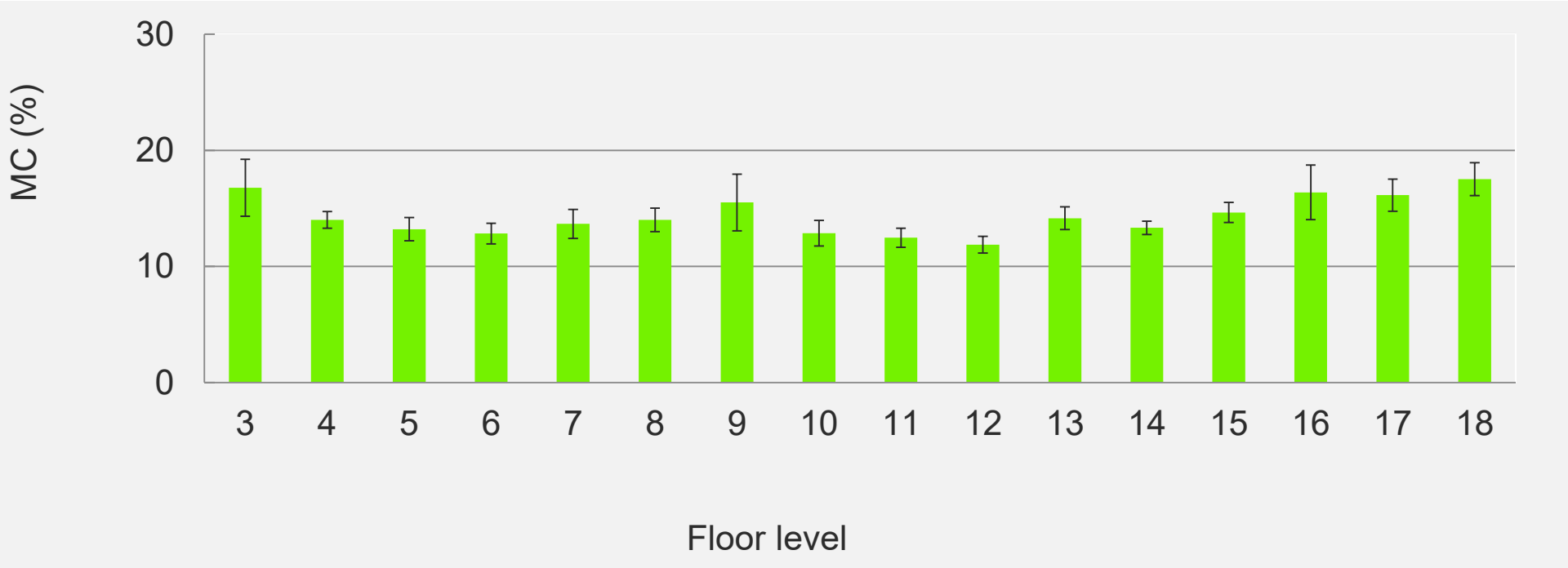
- Good coordination and sequencing
  - A high level of prefabrication to reduce time of exposure at site
  - Materials delivered for just-in-time installation
  - Timbers installed in relatively warm and dry season (June-August 2016)
  - Exterior walls/roof installed quickly to protect timber structure

On-site Moisture Protection

- Additional on-site protection applied
  - Second water repellent applied at site
  - Joints/holes in CLT floor sealed with self-adhesive tape immediately after installation
  - Sink-style drains created on each floor

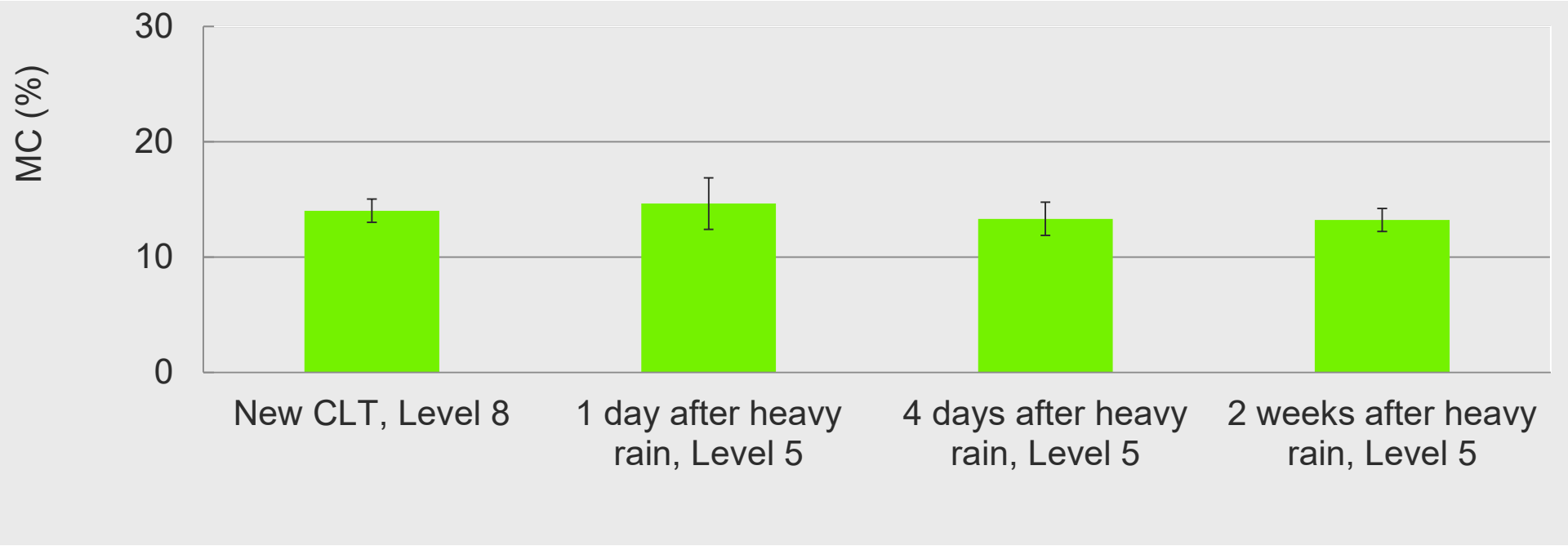
On-site Moisture Protection

- Site measurements showed wetting was overall slow in CLT (S-P-F) floors



Average MC measured from CLT of different floor levels (before concrete topping) from June 24 to September 1, 2016

On-site Moisture Protection



MC of CLT, measured from a newly installed floor (Level 8), and from Level 5 with 1, 4 and 14 days after a heavy rain event

Design to Promote Drying Important

- Drying potential varies with product/treatment
- Design has a large impact on drying, e.g.,
  - Use of built-up members
  - Using low-permeance products (e.g., low-permeance insulation, impermeable membrane)

Design to Promote Drying Important

- Design for drying is particularly important for mass timber assembly
  - Slow drying once wetted
  - e.g., interior ventilation cavity in mass timber roof

Plywood furring used to create an air space between plywood roof sheathing and CLT panels

Wood Innovation and Design Centre, Prince George, Canada

Courtesy: Michael Green Architecture

Conclusions/Messages

- MC of dimension lumber remained 20% on average in wet season, 15% in dry season in light wood-frame construction
- Preventing wetting is a high priority over accelerating drying
  - Drying is slow once severe wetting occurs
  - On-site protection important
- Materials/assemblies, susceptible to wetting and poor drying, require better on-site protection
- Some levels of protection may be provided by sheathing or membrane, if a temporary roof is not possible
- Always design assemblies with good drying capacity, since protection against wetting cannot be perfect

Acknowledgments

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- Assistance from RDH Building Engineering, Morrison Hershfield, SMT Research, material suppliers, developers, construction companies, engineers, and architects involved

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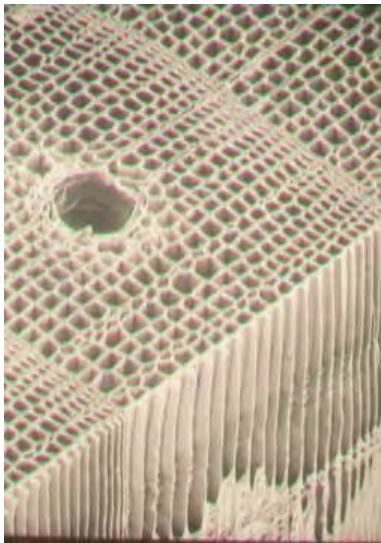
Wood and Water

- In freshly cut wood (green wood):
  - Liquid water in cell cavity (“free water” or “capillary water”), evaporates first during drying
  - Water in cell walls (“bound water” or “hygroscopic water”), more difficult to dry
- Fibre saturation point
  - Cells walls are fully saturated with water but no liquid water in cell cavity
  - Moisture content around 30%



Wood and Water

- Wood moisture content (MC)
  - The amount of moisture in wood, expressed as a percentage of the mass of the wood *(after oven drying at 103°C)*
  - MC measured with a portable moisture meter or sensors during construction

Wood and Water

- Measuring MC with a moisture meter
  - Typical measurement range for solid wood: 6-25%
  - Measurement less accurate beyond this range; on composites or treated wood

capacitance-based meter
(e.g., Wagner)

resistance-based meter
(e.g., Delmhorst)

Wood and Water

- Wetting?
  - Exposure to a moisture source, wood reaches a risky MC, typically close to or above 30%
- Liquid water is a major cause of wetting
  - Rain, ground water, melting snow, condensation
  - Water once absorbed quickly increases local MC
- Risk of construction moisture is high in a coastal climate

Wood and Water

Pathways of liquid water into wood:

- Most rapidly through end grain
  - Exposed by end cuts, notching etc.
- Much slowly through other surfaces
- Checking may create water traps

Beam

End grain

Wood and Water

Wood products have different wetting potential:

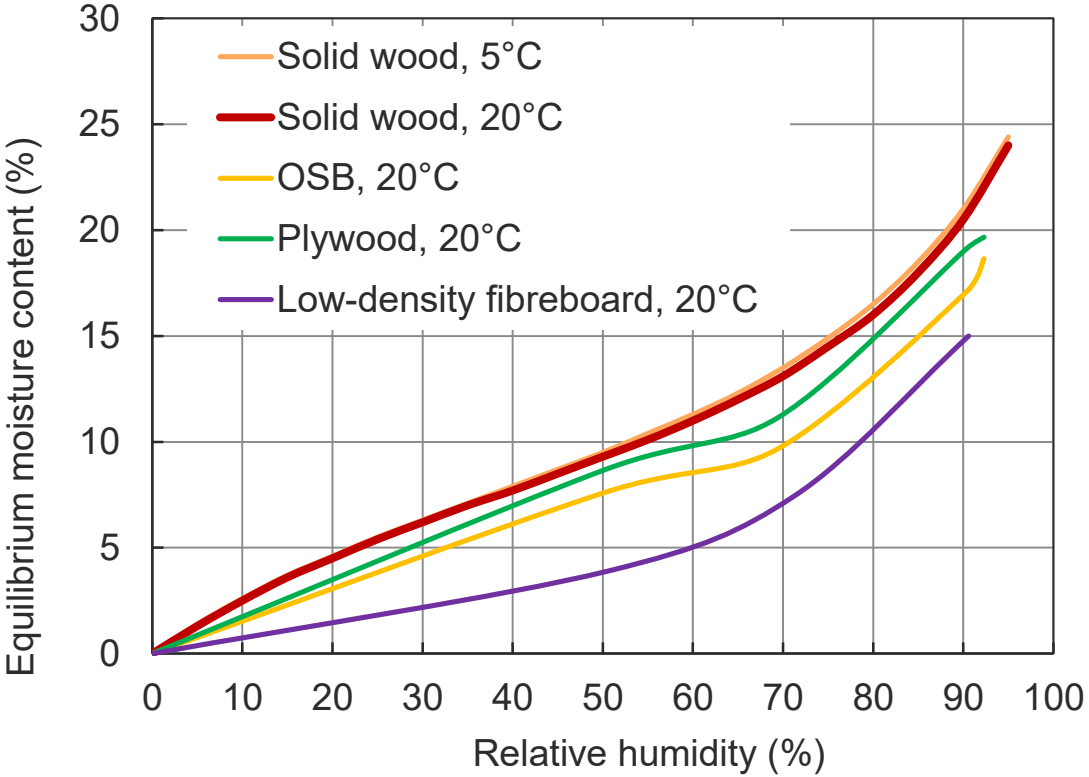
- Dimension lumber/solid-sawn timber
  - Wood species, amount of sapwood vs. heartwood
  - Overall Canadian softwoods not permeable
- Engineered wood
  - Solid wood-based, or composites
  - Voids, end grain exposure, adhesive, wax…
- Build-up assemblies
  - e.g., nail-laminated timber, with small gaps inside
- Finishing/wrapping: water repellant, tarp…

Wood and Water

- In addition to liquid water, wood interacts with vapour in the air (i.e., sorption)
  - Wood gains moisture in high humidity environment
    - Also a source of wetting, but a slower process
  - Wood loses moisture in low humidity environment
    - It is the means of drying (evaporation)
    - An important aspect of keeping wood dry

Wood and Water

- Sorption curve: equilibrium moisture content at given RH and temperature
  - RH is a major factor for EMC
  - Material matters



Wood and Water

Typical MC ranges at manufacture (*Introduction to Wood Design*)

Material/assembly	MC range
Dimension lumber, “S-Dry” (including “KD”)	15-19%
Solid-sawn timbers	Subject to supply agreement, typically above 30% (fibre saturation point) for green timber posts
Glued-laminated solid wood products, such as glulam, cross-laminated timber (CLT)	11-15%
Sheathing panels, such as plywood, OSB, fiberboard	6-12%
Structural composite products, such as parallel strand lumber, laminated strand lumber, oriented strand lumber, laminated veneer lumber (LVL)	6-12%
Large built-up members: Nail-laminated timber (NLT)	6-19%

Wood and Water

Equilibrium moisture content in different climates (*cwc*)

Location in Canada		Average EMC (%)	Winter EMC (%)	Summer EMC (%)
West coast	indoors	10 – 11	8	12
	sheltered outdoors	15 – 16	18	13
Prairies (e.g., Alberta)	indoors	6 – 7	5	8
	sheltered outdoors	11 – 12	12	10
Central (e.g., Ontario, Quebec)	indoors	7 – 8	5	10
	sheltered outdoors	13 – 14	17	10
East coast	indoors	8 – 9	7	10
	sheltered outdoors	14 – 15	19	12