On-Site Moisture Management of Wood Construction

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SUMMARY

This is a principles-based document that provides guidelines and relevant information about on-site moisture management practices that can be adapted to suit a range of wood construction projects. The document aims to help designers and construction companies/builders assess the potential for moisture-related issues arising during the construction phase of a wood building project and identify the appropriate actions to mitigate such risk. Several categories of wood materials/built-up assemblies are classified based on their properties related to water absorption, entrapment, and drying potentials. Different levels of protection strategies and methods are provided for consideration depending on the risk associated with durability, or discolouration of appearance components, resulting from wetting incidents. This guide largely focuses on mass timber construction but also covers light wood-frame buildings.

The most critical factors that should be taken into consideration in determining appropriate on-site protection include:

- Construction weather conditions (e.g., rain, snow)
- Wetting potential (water absorption, entrapment) of the wood materials/built-up assemblies
- Drying ability of the wood material/built-up assemblies
- Durability-related risk (e.g., mould, decay) after wetting
- Appearance deterioration risk (e.g., discolouration) for exposed wood members and finishing materials
- Location of the assembly in the building (e.g., interior/exterior wall, upper/lower floor, roof) and associated impacts on exposure and drying
- Cost of construction delay (or time to building lockup stage)
- Cost of potential remediation
- Cost of forced drying (e.g., space heating, dehumidification, mechanical ventilation)
- Cost of protection methods and required coordination

In addition to selecting suitable materials/built-up assemblies and on-site protection, all assemblies should be designed to dry, in case wetting occurs during construction or in service. This is particularly important for materials and assemblies, which are highly susceptible to wetting and very slow in drying, and will require costly remedial treatments after wetting incidents. Ideally, several measures should be employed, as they are typically not fully effective all the time. Although design is an important step, the design aspect is not a focus of this document.

1 INTRODUCTION

It is important to protect wood from water during the transport, storage, construction, and in-service stages to prevent potential issues, such as staining, mould, excessive dimensional changes, and decay. Among these stages, adequate on-site moisture protection is likely the most challenging given the range of possible moisture exposure conditions and the inevitable site and cost constraints of a construction project. Limited guidance is available (BRANZ 2004; CWC 2004), particularly related to the construction of large and tall wood buildings in a rainy coastal climate, or a northern climate with heavy snow loads. Moisture safety, especially during construction, was reported to be an urgent issue that deserves attention based on the experience with tall timber buildings in Europe (FII and BSLC 2014; Winter 2014). Figure 1 illustrates a general process and considerations for assessing the risk associated with on-site wetting and the subsequent decision making. Following this sequence the document summarizes moisture-related information about wood products/assemblies seen on construction sites, several categories of products/assemblies classified based on wetting and drying potentials, and different levels of on-site protection that may be applied.

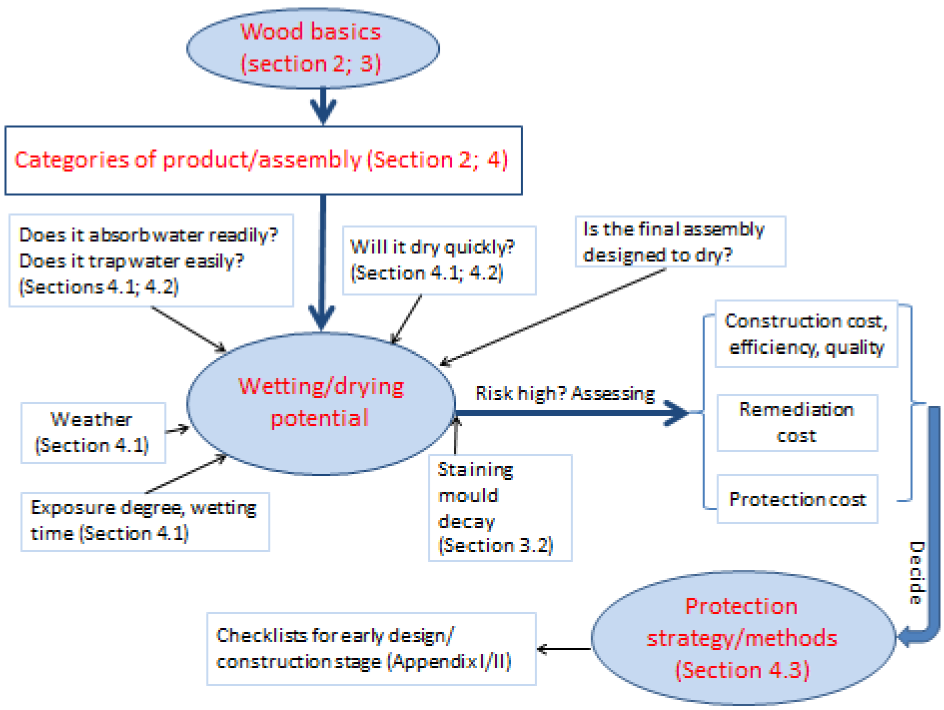

Figure 1 General sequence of assessing wetting and durability risks and determining on-site protection strategies and methods

It is well known that a building assembly (e.g., roof, floor, and wall) should not be enclosed until the wood has dried to an acceptable level of moisture content (MC), typically below 19%[1]. The figure "19%" means that the mass of water present in a piece of wood is 19% of the mass of the wood after it has been oven-dried. Excessive moisture may cause staining, mould growth, and ultimately decay if it does not dry out, or issues such as excessive dimensional changes (e.g., nail popping, drywall cracking) and corrosion of fasteners. However, wood is in general quite resilient to moisture and MC changes if kept

[1] More information on measuring moisture content is discussed in Section 3.3.

within certain limits. Wetting of framing during construction should not lead to problems if certain conditions are met. In previous decades the use of green wood (the wood that is recently cut and has not been purposely dried), including dimension lumber and solid timbers, was the norm in most regions of North America (see the Canadian survey report, Garrahan et al. 1991)[2]. Exposing wood during construction, which added probably only a small amount of moisture to the wood, never got much attention. Most potential issues were solved, in a natural way, by the generally slower pace of construction at the time, which allowed wood in an assembly to dry before the assembly or building is enclosed. In addition, the traditional building envelope, which used to have very low levels of thermal insulation but typically high vapour permeance, also allowed the wood to continue drying after enclosure. Stick-built light wood-frame construction, mostly used for single family houses and low-rise buildings, can generally accommodate wetting well, even for the dried wood commodities (e.g., dimension lumber and sheathing panels) seen on construction sites today. Most wood, particularly solid wood products with surface wetting only, and thin panels, can dry quickly under favourable environmental conditions.

However, moisture management during construction has become more and more important with the increase in building height and area (which potentially prolongs the exposure to inclement weather), and the overall increase in the speed of construction which may not allow adequate time for drying to occur. In addition, the drying capacities of modern assemblies may have reduced resulting from increased insulation levels to meet more stringent energy efficiency requirements, or the use of membrane or insulation products with low vapour permeance. Even before enclosure, the drying of wood can be very slow in a cold and wet climate, especially for large wood members and fabricated assemblies that may contain many locations for water to be trapped or pool. Some construction companies use mechanical methods, such as space heating, dehumidification, and ventilation to dry wetted wood and speed up construction. This usually adds a considerable cost and may also bring other issues. Aside from framing members that are typically covered after enclosure, appearance members often require costly remedial treatment to remove staining and to refinish after incidental wetting. Appropriate on-site protection can minimize or avoid all these unexpected construction needs and costs. This is particularly important for the construction of modern larger and taller wood buildings.

2 WOOD PRODUCTS USED IN CONSTRUCTION

2.1 Material Classifications

Wood products and assemblies used in modern construction can be generally classified into the following categories based on the nature of the materials (i.e., water absorption, entrapment, and drying potentials). They are listed below in order of the level of protection that may be required on construction sites. See Section 3 for related wood basics and Section 4 for discussions about wetting and drying potentials and recommendations for on-site protection. In addition to the wood material itself, the layout of the assemblies and type of materials surrounding the wood also have an impact on the drying performance. These are considerations during the design. The design aspect is not the focus of this document although it plays an important role.

[2] Green wood is still used for wood construction in some areas of North America, such as California.

- ***Group A: Solid wood***
    1. Group A1: Dimension lumber, typically nominal 2 inch (38 mm) in thickness
    2. Group A2: Solid-sawn heavy timbers, such as Douglas fir, eastern white pine, and western hemlock posts and beams, typically 4-1/2 inch (114 mm) or more in its smallest dimension
- ***Group B: Glue-laminated solid wood products***
    3. Group B1: Glued-laminated timber (glulam)
    4. Group B2: Cross-laminated timber (CLT)
- ***Group C: Wood-based composites***
    5. Group C1: Traditional sheathing panels, such as plywood, oriented strand board (OSB), and fiberboard, typically with a thickness below 3/4 inch (19 mm)
    6. Group C2: Large structural composite lumber (SCL) products, such as parallel strand lumber (PSL), laminated strand lumber (LSL), oriented strand lumber (OSL), and laminated veneer lumber (LVL)
- ***Group D: Prefabricated assemblies***
    7. Group D1: Prefabricated light wood framing primarily using dimension lumber and sheathing panels
    8. Group D2: Large nail-laminated members with lumber and plywood, typically used as floor/roof decks
    9. Group D3: Prefabricated closed assemblies, i.e., modular home assemblies, which integrate insulation, membranes, and other materials

2.2 Moisture Content at Manufacture

Wood products have different MC specifications at the time of manufacture. In North America, structural dimension lumber (e.g., Spruce-Pine-Fir (S-P-F), Douglas Fir-Larch (D. Fir-L), Hem-Fir) is produced with the designation of either “S-Dry” (Surfaced Dry) or “S-Grn” (Surfaced Green). Lumber with designation of “S-Dry” means its MC is 19% or lower when it is planed or surfaced to the standard lumber dimension. Among “S-Dry”, “KD” (Kiln Dried) on a North American grade stamp indicates that the lumber has been kiln-dried to a MC of 19% or lower, typically targeting an average MC of 16%. “S-Grn” is not checked for MC at the time of surfacing but the MC is typically above 30% (additional moisture above approximately this MC level does not cause further expansion of the wood; see Section 3). The MC of solid-sawn timbers is subject to the agreement between the contractor and the supplier. They are typically supplied “green” without kiln drying or air drying, with an average MC above 30%. When dimension lumber or timbers are preservative-treated, they typically have a high MC upon arrival at a construction site.

Engineered wood products are manufactured to have lower and more consistent MC than lumber and solid-sawn timbers. The manufacture has more strict moisture control requirements for achieving proper adhesive bonding to target a narrower range of strength properties. Laminated solid wood products, including glulam and CLT panels, are manufactured at MC levels from 11% to 15%. SCL, such as plywood, OSB, LVL, LSL, OSL, and PSL, are manufactured with MC levels lower than or close to the equilibrium moisture content (EMC) in service, typically from 6% to 12%. Engineered wood I-joists are typically made using kiln-dried lumber or SCL (e.g. LVL) for flanges and plywood or OSB for webs. Prefabrication of the framing alone, or of closed assemblies including insulation, membranes, and other materials, usually has more consistent control over wood MC under sheltered or conditioned environments. The wood typically has a MC below 15%; lower MCs, such as 12%, may be achieved when specified.

Figure 2 Prefabrication of building assemblies in a factory

Table 1 lists typical MC ranges at the time of manufacture. ***However, it must be recognized that there is no assurance that the MC of wood will not change after manufacture.*** Green or "S-Dry" products usually continue to lose moisture as they adapt to the environmental conditions, provided they are kept away from liquid water sources. However, the MC of wood, particularly composite products, will usually increase resulting from short-term exposure to liquid water during construction, or more commonly, higher humidity than that during manufacturing. In order to fully benefit from using dried products, care must be taken to prevent them from wetting during shipping, storage, and construction.

Table 1: Typical MC ranges of wood materials at manufacture

Group	Major material/assembly examples	MC range
A1	Dimension lumber, "S-Dry" (including "KD")	15-19%
A2	Solid-sawn timbers	Subject to supply agreement, typically above 30% for green timber posts
B1/B2	Glued-laminated timbers, such as glued-laminated timber (glulam) and cross-laminated timber (CLT)	11-15%
C1	Sheathing panels, such as plywood, OSB, fiberboard	6-12%
C2	Structural composite products, such as parallel strand lumber (PSL), laminated strand lumber (LSL), oriented strand lumber (OSL), laminated veneer lumber (LVL)	6-12%
D1	Prefabricated light wood framing using dimension lumber and sheathing panels	6-19%
D2	Nail-laminated assemblies built with "S-Dry" dimension lumber and sheathing panels	6-19%
D3	Prefabricated closed assemblies	6-19%

3 WOOD BASICS

3.1 Wood and Moisture

Moisture exists in wood either as bound water (i.e., hygroscopic water) that is held within the cell walls or as free water (i.e., capillary water) that is stored in the cell cavities. As freshly cut (green) wood dries, the free water evaporates first. Wood reaches the fibre saturation point when all of the free water is gone, leaving only the bound water within the cell walls. The fibre saturation point averages about 30% among different wood species (FPL 2010), and 28% is commonly used for design-related calculations (CWC 2005). The practical importance of this concept is it marks a turning point of a relationship curve between most physical (e.g., shrinkage, swelling), or mechanical properties, and MC. These properties only change with the change of the amount of bound water in cell walls.

Wood exchanges moisture only with the surrounding air when it is not in contact with liquid water. Wood loses moisture, which could include free water, when present, and bound water, when the ambient humidity is low. The relative humidity (RH) drops as the temperature increases with other factors remaining the same in an environment. The drying of wood is fastest under warm, dry, and ventilated conditions. On the other hand, wood may gain moisture, which only becomes bound water, when the ambient humidity is high. The interactions with the water vapour in the air are called sorption, including both desorption, i.e., the loss of bound water, and adsorption, i.e., the gain of bound water. ***For pre-dried wood, the moisture in the air does not introduce liquid water and will not increase the MC above 30%, unless the vapour condenses on the wood surfaces under extreme conditions and the wood is exposed to liquid water long enough.***

Under constant humidity and temperature conditions, the wood will achieve an EMC when it no longer gains or loses moisture (i.e., when there is a balance between desorption and adsorption). In practice wood never reaches an EMC under the fluctuating environmental conditions encountered in construction. However, because wood gains and loses moisture slowly, the MC will normally fluctuate over a small range within a certain environment, and this stable MC can be considered an EMC in practice. Figure 3 shows the average EMC, i.e., isothermal sorption curves of solid softwood (e.g., S-P-F, Douglas fir) with changes in RH at two levels of temperature (with data based on FPL 2010). The EMC of wood is primarily determined by the RH of the environment. Other factors including temperature (under a given RH), wood species, and drying history all have small effects and can be neglected for practical purposes. Figure 3 also includes the EMC of OSB, plywood, and a type of low-density fibreboard (with data based on Kumaran 2002). Wood-based composite products usually have an EMC lower than that of the parent wood material due to the added chemicals (e.g., adhesive, wax) and the high temperature treatment during manufacture (Onysko et al. 2010). Related to this sorption behavior, Table 2 provides typical MC ranges under outdoor sheltered or indoor environmental conditions in different climates in Canada (from CWC 2005, Table 5.3). However, when wood is exposed on a construction site, liquid water sources (e.g., rain, snow) usually play a more controlling role in the performance than sorption alone. See Section 4.1 and 4.2 for detailed discussions.

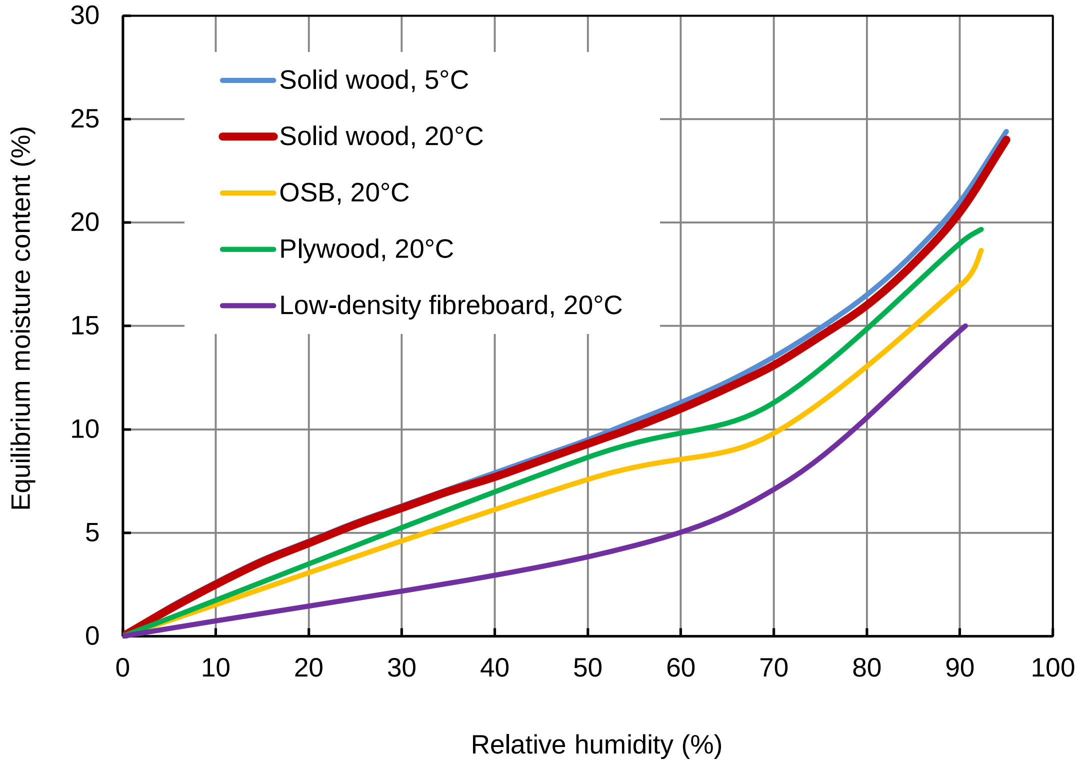

Figure 3 Representative isothermal sorption curves: equilibrium moisture content of solid wood and wood-based composites at various relative humidity levels (data sources: FPL 2010; Kumaran 2002)

Table 2: Typical equilibrium moisture content ranges of wood materials in different climates (from CWC 2005)

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

3.2 Durability: How Much Moisture is Too Much?

Durability of wood components in this context primarily means resistance to fungi, such as staining, mould, and decay fungi. The most important conditions for fungi to grow in wood are suitable moisture and temperature conditions (Morris 1998; FPL 2010). ***Preventing extended exposure to moisture is***

the key to preventing most durability issues throughout construction and service life. The most serious bio-deterioration, decay, affects strength. It generally requires wood cell walls full of bound water and some free water inside wood cell lumens, with a minimum MC of approximately 26%, for decay fungi to initiate and progress in wood; it then takes months for detectable structural damage to occur under marginal conditions (Wang et al. 2010). However, when there is a larger amount of free water available with a MC ranging from 40% to 80%, decay and consequent strength loss can occur rapidly (e.g., in weeks in susceptible wood species). Compared with decay, mould or staining does not affect wood strength. Mould growth is more associated with the RH of the environment, more specifically, the surface RH (sometimes called "water activity") of the building components. It needs a minimum surface RH around 80% to grow on wood at a temperature of 20-25°C; under such marginal conditions, it could take months or longer for mould to initiate on non-resistant wood materials (Nielsen et al. 2004). Incidents of mould growth or other types of fungal staining occurring during construction are more often associated with wetting caused by liquid water sources (e.g., rain, condensation). Aside from fungi, discolouration can also be caused by metals, in combination with moisture, such as iron staining (Figure 4). For appearance products and exposed members, discolouration is often a major concern resulting from incidental wetting and often requires costly remediation treatment.

Figure 4 Iron staining on glulam resulting from on-site wetting and contamination with iron particles

Under the same external conditions, different types of wood have different inherent resistance against mould or decay, primarily due to extractives in the wood. Sapwood is the newer part of a tree, closer to the bark (See Figure 5). Generally the sapwood of any wood species has low natural durability. Heartwood is the inner, older part and no longer alive in the tree. The heartwood is more durable than the sapwood for a given wood species; however, wood species vary widely in the natural durability of their heartwood (FPL 2010). Relative to most commercial softwood species, the heartwood of S-P-F and Hem-Fir is less durable; the heartwood of Douglas fir and western larch is moderately durable; and the heartwood of species, such as western red cedar and yellow cedar, has high natural resistance to decay. Most Canadian softwood species used for construction are predominant with heartwood, with relatively narrow sapwood. When the wood is not naturally durable enough to prevent fungal attack, it can be treated with chemicals, such as mouldicides or preservatives, to improve its durability against mould or decay. More information about natural durability and preservative treatment can be found at www.durable-wood.com.

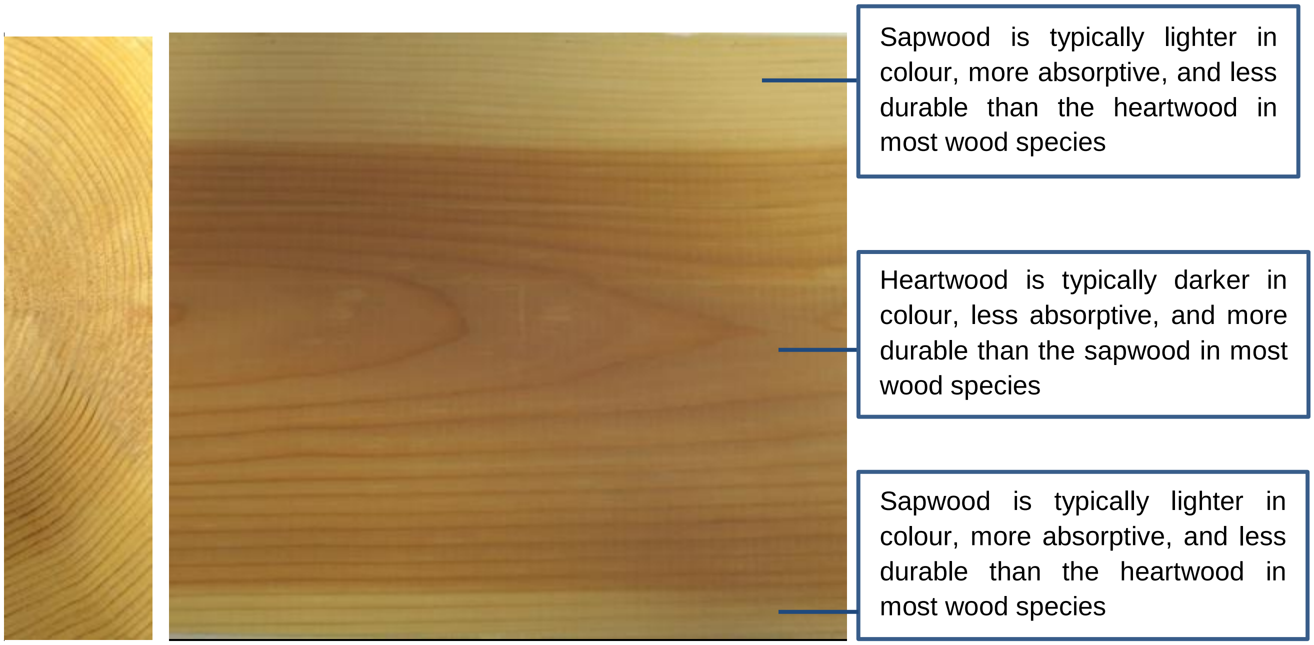

Figure 5 Sapwood and heartwood in a piece of Douglas fir lumber (left: end grain; right: tangential surface)

In addition to the effects of chemical compositions, inherent moisture-related properties, such as sorption and water absorption, affect the durability. Water is also never uniformly distributed throughout a piece of wood. For example, the sapwood of most species is relatively more absorptive than the heartwood. Due to the complicating effects of inherent properties and external conditions on the durability performance of wood materials, it is not easy to make a clear definition of how much moisture is too much. ***The locations which tend to get in contact with and trap liquid water, and reach and retain a MC close to or higher than 30%, such as end grains and various joints, typically start to deteriorate sooner, especially under warm conditions.*** These locations deserve special attention and protection measures.

3.3 On-Site MC Measurement

The MC of wood should be measured and monitored on a construction site to help make informed decisions about protection and drying needs. The MC of solid wood members can be measured by using a portable moisture meter typically based on electrical resistance (i.e., moisture sensor pins) or capacitance. The measurement should be conducted away from wood defects, such as knots and pitch pockets. Most resistance-based meters require the two pins be inserted parallel to the grain. When the metal pins are not coated, i.e., non-insulated, they provide the highest MC reading of the wood between the two pins. When the pins are coated with a non-conducting material except at the tips, i.e., insulated, they measure the MC between the two tips and thereby may provide moisture readings at specific locations inside the wood (Figure 6, right)[3]. Such functions can be important to detect moisture

[3] Internal MC measurement may be particularly important when monitoring a member that was severely wetted to the core (or originally manufactured green) and is currently drying. In this case, the MC varies from the core to the surface and a measurement with an insulated pin except at the tip can provide a good estimate of the average.

entrapped inside a member or an assembly. A capacitance-based meter covers a large volume of wood, typically an area about equal to the meter's footprint to a depth of about 25 mm. It is usually quicker and easier to use on a construction site (Figure 6, left). It also has the advantage of not leaving pin holes in the wood. When properly calibrated, both types of moisture meters have a working range from 6% to 25%, with errors approximately ± 2%. Some meters can provide higher readings, for example, 40-50%, often with reduced accuracy. When conditions allow, the measurement should be adjusted for the effects of wood species and temperature. Comprehensive information about MC measurement is available in literature (James 1988; Garrahan 1988; Forintek Canada Corp. 2001; Onysko et al. 2010; FPL 2010; ASTM 2013). Note that special consideration and calibrations are required for measuring MC of wood-based composites, such as plywood and OSB, as well as treated wood (e.g. preservatives- or fire retardant-treated wood), due to effects of the chemicals on electrical conductivity or capacitance (Forintek Canada Corp. 2001; Onysko et al. 2010).

Figure 6 Measuring wood moisture content using a capacitance-based meter (left) and a resistance-based meter (right)

4 ON-SITE PROTECTION FOR DIFFERENT CATEGORIES OF WOOD

The highest priority for wood protection at a construction site is to reduce wetting; re-drying may become necessary or a priority after wetting has occurred. Table 3 generally summarizes the wetting and drying potentials, appearance deterioration potential, and the protection requirements for the different categories of wood materials/assemblies described in Section 2.1. As discussed in detail below, the nature of the materials used and how they are built-up into assemblies both play a role in determining the wetting (i.e., water absorption and entrapment) and drying properties (Sections 4.1 and 4.2). This may consequently dictate different levels of protection on site (Section 4.3), when the drying performance of the final assemblies and other conditions are also taken into account. Potential remediation needs and costs should also be considered.

Table 3: Potentials of water absorption/entrapment, appearance deterioration, and drying under favourable conditions, and protection requirements under typical construction conditions

Group	Examples	Water absorption/ entrapment potential	Appearance deterioration potential	Drying rate	Protection requirements
A1, Dimension lumber, reference material in this table	"S-Dry" S-P-F	Low	Low. Will be enclosed	Fast after surface wetting	Basic measures
A2, Solid-sawn timbers	Unfinished Douglas-fir balcony posts	Low	Low. Will be covered or finished	Fast after surface wetting, but slow from green timbers, or after deep wetting, or after enclosure	Basic measures, e.g., keeping them away from liquid water and providing good ventilation
B1 and B2, Glued solid wood members	Glulam, CLT	Medium. It will increase if there are absorptive mechanisms (e.g., gaps and sapwood) inside.	Medium for unfinished but very high for finished members	Fast after surface wetting but slow after deep wetting or enclosure	From basic measures to more advanced measures. For coated members, the priming coat should be pre-applied in factory, but the top coat should be applied at the site to reduce damage.
C1, Thin sheathing panels	Plywood, OSB	Very high absorption	Low. Will be enclosed	Medium	Basic measures, e.g., edge sealing, keeping them away from liquid water and providing good ventilation
C2, Large composite members	PSL, LSL, OSL, LVL	High absorption potential	Very high for finished members	Fast after surface wetting but very slow after deep wetting or enclosure	Advanced measures, such as pre-installing membrane or using a temporary roof. Choose dry weather for installation.

D1, Prefabricated light wood framing	Pre-framed wall, floor and roof assemblies using dimension lumber and sheathing panels	From low to high. Joints may trap moisture.	Low. Will be enclosed	Medium. Fast after surface wetting but slow after deep wetting or enclosure	Basic measures, e.g., keeping them away from liquid water and providing good ventilation
D2, Large built-up members	Nail-laminated timber floors /roofs, double-layer plywood decks	Very high moisture entrapment potential	Very high for finished members	Fast after surface wetting but very slow after deep wetting or enclosure	Advanced measures, such as pre-installing membrane or using a temporary roof. Choose dry weather for installation.
D3, Prefabricated closed assemblies	Fully prefabricated walls and floors	Typically low, if all joints are sealed properly; but very high for unsealed joints	Very high for finished components	Slow. Will require opening assemblies to dry wetted materials	It depends on the assemblies and wetting potentials. Choose dry weather for installation.

4.1 External and Internal Factors Affecting Wetting and Drying Behaviour

Wetting in this context occurs resulting from exposure to liquid water, such as rain and snow (i.e., once melted) during construction. The winter rainy climates in the coastal areas, with long periods of rainy days, impose very large moisture loads on materials and assemblies exposed on site. The wetting and drying potentials of a given material depend on weather conditions, such as the frequency of rain (e.g., rainy days during construction), rainfall amounts, humidity levels, wind speed, and temperature. Wood usually needs time to absorb water; to increase its MC, the period of wetting is therefore often more important than the total amount of water falling on the surface (Scheffer 1971). Related to weather conditions and exposure degrees, the orientation and location of components have a large impact on the wetting and drying potentials. For example, horizontal components, such as roofs and subflooring, are often subjected to more rain (and pooling) and need more time to dry after wetting events. Mass timber roofs are particularly slow to dry once the wetted wood members are covered with roofing materials, which typically have low vapour permeance. By comparison, vertical components, such as wall sheathing, typically receive smaller amounts of rain (mostly wind-driven rain) and can also dry relatively quickly. Components on ground are typically subjected to severe wetting resulting from exposure to standing water and other moisture sources. Snow can be a significant wetting source in areas with heavy snow loads. It does not result in much wetting until it melts, so the most important measure is to remove snow from wood before it melts.

Different materials/assemblies absorb and trap water, as well as dry at different rates (Wang 2014). The speed of absorption, depth of water penetration, and the amount of moisture retained during exposure to rain and other water sources largely depend on inherent factors, such as method of manufacturing; wood species; dimensions; presence of internal voids; exposure of end grains; adhesive and wax contents for composite materials; and, if applicable, surface treatment. All these factors can affect the resistance to water absorption at the surfaces and the internal resistance to moisture movement and distribution.

Factors increasing the likelihood for moisture to penetrate deep into the wood components, thus slowing the drying ability and consequently leading to potential decay include:

- End grains, which are the most absorptive, exposed on tops of vertical components and ends of horizontal components, or embedded into or in direct contact with ground, concrete, masonry that will stay damp
- Combination of end grains and water traps at joints
- Interconnecting voids and gaps within engineered wood products, particularly when the more absorptive sapwood (than heartwood) is adjacent
- Delaminated engineered wood products due to shrinkage and other moisture-related stresses
- Checking in sawn timbers and, to a lesser extent, in glulam and other products
- Wood members that have become wet and then have reduced drying rates due to:
  - A large size or being massive
  - Gaps between members (e.g. in built-up members) that permit moisture penetration but limit air flow
  - Materials with low vapour permeance, such as low-permeance membranes, closed-cell spray foam, and extruded polystyrene that are used to cover the wet member

The best materials/assemblies not only do not pick up or trap water easily, but also dry quickly. For any wood species and products, the end grains usually allow water to go deeper and deserve special treatment. The edges of lumber or timbers often contact and absorb water first. Sapwood is typically more absorptive than heartwood and may create special risks when it is present inside. Many materials absorb water easily and also dry readily when conditions allow. But it should be noted that drying rates generally occur at a lower order of magnitude than wetting rates, even under warm, dry, and ventilated conditions. Moreover, modern construction schedules may not provide sufficient time for drying, especially when combined with weather conditions that are not favourable for water evaporation. Large dimension members and built-up assemblies (see Section 4.2) often have high wetting and low drying potential once water is allowed to penetrate deeply. In addition to material selection and on-site protection, the assemblies must be designed to dry inward, outward, or both inward and outward. This can be achieved, for example, by using vapour permeable materials (e.g., insulation, membrane) and integrating exterior or interior ventilation functions (e.g., a rainscreen cavity) (HPO 2011; Finch et al. 2013) in case wetting occurs during construction or in service.

4.2 Wetting and Drying Potentials of Different Categories of Wood

Group A1, Dimension lumber of Canadian softwood species, such as S-P-F, D. Fir-L, and Hem-Fir, generally have a higher resistance to water absorption and penetration than the more permeable pines, such as southern pines and radiata pine (typically with wider sapwood), or the more permeable hardwood species, such as aspen and birch. Based on the experience with pressure preservative treatment, water does not penetrate lumber of refractory species, such as S-P-F and Douglas fir, more than a few millimeters even after 6 hrs under a pressure of 1035 kPa, unless the wood is mechanically perforated before treatment (Morris 1991). But long exposure time (e.g., weeks) will lead to deep wetting and large amounts of water absorbed. The blue-stained sapwood of beetle-killed lodgepole pine typically has increased water permeability (McFarling et al. 2006). It was reported that the average MC of "S-P-F" dimension lumber (studs and bottom plates, "S-Dry") was about 20% during wood-frame construction in winter in Coastal British Columbia, before the building was protected from rain (Wang et al. 2013). However, there was a wide range in the MC depending on exposure degrees, with the higher readings above 30%. The average MC of lumber dropped to about 15%, with a much narrower range than that observed in the winter, under the summer drier conditions in the same area (Wang and Ni 2014).

Group A2, Solid-sawn timbers, are similar to dimension lumber (Group A1) in terms of wetting and drying potentials for the same material, but with additional influence from the larger dimensions. These products generally require good conditions (e.g., ventilation) to dry while being kept away from water sources, particularly when they are supplied "green" without pre-drying. When dry products are exposed to water for long periods of time (e.g., weeks), water gets deep into the wood, and the subsequent drying can be very slow.

Groups B, C, and D, i.e., glue-laminated, build-up, or prefabricated products/assemblies, generally have many advantages for industrial and commercial construction. For example, big members are readily available, or can be conveniently assembled for large spans. However, those products/assemblies often require special care during storage, transportation, and construction to prevent structural damage and other potential issues, such as excessive wetting and discolouration, compared with dimension lumber and solid-sawn timbers.

In further detail, ***Group B1 and B2, glued solid wood products*** (e.g., glulam, CLT) made with Canadian softwood species generally exhibit the similarly low wetting potential as Group A products (McClung et al. 2014; Wang 2014). When glulam and CLTs are installed to take advantage of their visual appearance, incidental wetting often causes discolouration, particularly in association with iron staining, requiring remediation (e.g., sanding and refinishing). Small gaps between boards of a CLT panel may increase water uptake and reduce drying resulting from capillary effects, particularly when they are oriented horizontally. On the other hand, larger gaps between joints, such as 5 mm for Norway spruce, were reported to improve the drying (Fredriksson et al. 2013). Edge-gluing the boards, particularly on the faces of CLT panels, can increase water resistance as well as airtightness; however, this may result in more random drying checks. When glulam and CLT are subjected to long periods of wetting (e.g., weeks) enabling deep water penetration, or when low-permeance materials (e.g., insulation, membrane) enclose a member that contains a large amount of moisture, the subsequent drying will be very slow. This can lead to excessive damage and must be avoided.

For **Group C**, composite products, such as plywood, OSB, PSL, and LSL, the micro-voids and the increased amounts of exposure of wood end grains that may be characteristics of certain products can make these products more susceptible to deep wetting, compared with solid wood products. On the other hand, the presence of adhesive and wax, if any, may considerably reduce water absorption. The dimensional stability of the product when exposed to moisture is also an important factor. For example, given the same exposed surface area and wetting conditions, plywood and OSB (Group C1) will be saturated with water more easily compared to thicker products; however, the thinner panels of plywood and OSB dry more quickly when conditions allow (Wang 2014). This is a main reason that it is usually not a major concern to see wet plywood or OSB in light wood-frame construction, but drying of big composite members (Group C2) can be a large concern and incur high cost. In addition, when large members are exposed for aesthetic reasons, staining from incidental wetting may require removal and refinishing. These large composite members therefore require much attention to prevent wetting during construction.

Group D, prefabricated framing or assemblies, are unique in terms of wetting and drying potentials. Prefabricated light wood framing of walls and floors (***Group D1***), typically built with dimension lumber and sheathing panels only, is commonly used for mid-rise wood-frame construction (e.g., 5- and 6-storey buildings, Figure 7). This is a great step above the traditional stick-built construction to improve construction efficiency. The reduced exposure time means the moisture penetration is relatively shallow and primarily in the surface, therefore, it can dry faster. Forced drying is effective and often used before enclosure in a cold and wet climate.

Group D2, large build-up assemblies, such as nail-laminated assemblies built with dimension lumber (with a plywood top layer, pre-installed or not), or built with double or more layers of plywood (or other panels), can be susceptible to excessive wetting. Water is easily trapped, particularly between the boards or between the plywood layers and the drying can be very slow (Wang 2014), even under heated conditions. Consequently fungal growth can start quickly in those risky locations. Such assemblies must therefore be carefully protected against rain during construction (Section 4.3). Special attention should also be paid in design to promote drying ability of the final assemblies.

Group D3, prefabricated closed assemblies and modular homes have been used, particularly in Europe and Eastern Canada, and offer many advantages for construction and on-site moisture management (Figure 8). Prefabrication, which can be carried out in a simple shelter or advanced factory environments, should be used whenever possible to improve construction efficiency and reduce exposure time. However, when the prefabrication includes materials, such as insulation and membranes, but is not made completely tight against moisture penetration, the materials other than the wood will also have a large effect on the wetting and drying performance. Most insulation and membrane products, and low-permeance materials (e.g., polyethylene, closed-cell spray foam, and extruded polystyrene) in particular, greatly slow down drying. Once the assemblies get wet in locations that are not visible, it typically becomes complicated and expensive to open the assemblies and dry materials before re-enclosure. Additional remedial treatments or replacements may be necessary if mould growth has started or any finishing material has discoloured.

Figure 7 Using prefabricated framing for multi-unit light wood-frame construction

Figure 8 Installing a modular roof for a house

4.3 Protection Strategies

The wetting and durability risk, protection needs, and costing for different levels of on-site protection as well as potential remediation should be assessed to make informed decisions based on the materials/assemblies used (see Table 3), climatic conditions during construction, and the final assemblies. Standards related to moisture management and other aspects of quality assurance on site have been developed in countries, such as Finland (Finnish Standards Association 2012). The Finnish standard requires that the construction company develop a moisture control plan and an assembly plan for wood materials used for load-bearing structures in co-ordination with manufacturers and designers. Both plans should include the expected level of on-site protection based on the design MC of wood. That includes, if the target MC is below 15% (which would include almost all wood elements in a conditioned indoor space), that the expected protection level would be Protection Level 3 (PL3). PL3 requires indoor conditions or a tent with heating to be created for construction.

In the North American context, there is no regulatory instruction for on-site moisture management. As a general recommendation, schedule the framing and enclosure in a drier season, whenever possible, to reduce wetting and promote natural drying. The following basic storage or protection measures should be taken into consideration in any type of wood construction:

- Coordinating material delivery for just-in-time installation to reduce on-site exposure time
- Keeping materials away from ground by always placing on dunnage with sufficient clearance to permit airflow under the packages
- End-sealing exposed end grains of wood members for temporary protection, such as by using a water repellent or a primer
- Using wraps and tarps to prevent rain ingress during storage and construction (see an example in Figure 9)
- Storing materials in well-ventilated shelters

Figure 9 Covered prefabricated framing at a construction site

Although advanced protection methods typically require more work and coordination and are more expensive, the effort may result in savings in time and effort elsewhere. Such methods should be considered for materials and assemblies that are highly susceptible to wetting and very slow in drying, and/or will require costly remedial treatments once wetting occurs. Examples of advanced protection measures include:

- Purposely utilizing the shell of the building (e.g., floors, roof, walls) for protection
- Sealing all surfaces, such as by using a water repellent or a primer, for temporary protection
- Pre-installing temporary or permanent protective membrane on a member or on an assembly
- Using a temporary roof for partial or the entire construction (an example shown in Figure 10)

Figure 10 Using a tent to protect roof construction in a recent Vancouver project

Whenever possible, exposure of wood products to the exterior weather should be minimized. Arrangements should be made for materials to be delivered just in time for installation to minimize storage needs and time, and to prevent potential wetting.

"S-Dry" lumber (***Group A1***) and engineered wood products (***Groups B and C***) are typically covered with wraps when the packages arrive at a site. The packages should ideally be kept in a shelter, using dunnage below to keep the wood off the ground. Wet wood should be properly stacked and kept under covered and ventilated conditions to accelerate drying. Some engineered wood products, such as glulam beams, should be placed at the site based on their final positions in the building. The wraps should be kept until the products are ready to be installed. When a wrap is opened, the cutting should prevent rain penetration but encourage drainage and drying (e.g., by cutting the wrap underneath), and the wood should be re-covered with waterproof tarps whenever possible. Check stored materials regularly. The wraps and tarps used for on-site protection should be breathable to allow drying; plastic wraps or tarps may trap moisture and slow down drying once water gets inside. Wood-based composite materials (***Group C***), large composite members (***Group C2***) in particular, require more attention during storage and handling than solid wood products.

When aesthetic coatings are used on large wood members, the priming coat should be pre-applied in the factory to serve as a temporary on-site protection, but the top coat is recommended to be applied at the site to reduce damage during construction. Factory finishing with a water repellent or a primer, particularly for the surfaces and edges which are more likely to be temporarily exposed to liquid water sources (e.g., rain, ground moisture, snow), may make the surfaces water-repellent and reduce water absorption within a short period of exposure. If a treatment makes wood surfaces slippery, it should be avoided on surfaces where there will be foot traffic during construction (e.g., subflooring, roof sheathing). As an alternative, pre-installed membrane, or even a temporary roof, may be used to provide better protection against moisture.

For a nail-laminated timber deck (***Group D2***), it is recommended that the top plywood needed to meet structural requirements (preferably tongue-and-groove) should be pre-installing in the factory to reduce the amount of water that can get trapped between the boards below. There are areas where the plywood connects adjacent nail-laminated timbers and can only be installed at the site. These areas should be kept to a minimum and the plywood should be installed as soon as the construction allows. Work should be coordinated to install the prefabricated assemblies under dry weather conditions and then protected using plastic tarps until the building is fully enclosed. Another solution would be to pre-install waterproofing membrane (as a temporary protection, or left in place if it is part of the permanent membrane or compatible with the final waterproofing systems) on the assemblies to reduce the wetting potential. The joints between the membranes of adjacent assemblies should be immediately sealed upon installation. This membrane should resist wear and tear and remain water resistant for the duration of construction. But the most robust means would be to install a temporary roof to shelter the part of construction having high risk. When such assemblies do get wet, circulating warm and dry air past the assemblies may help moisture evaporate from the laminated boards and between the lumber and the plywood. However, it may require considerable effort to remove the trapped moisture.

The upper surfaces of large horizontal members or panels of a floor or a roof (***Groups B1, B2, C1, C2, D1, D2***) may have a protective membrane (e.g. plastic or fabric-type membrane, or a liquid-applied membrane when suitable) applied before installation. Any joints and interfaces should be sealed immediately once such members or panels are installed to prevent rain and melt water from seeping through gaps and getting trapped within the wood members. Ideally this selected protective membrane will serve permanently as part of the designed assembly. For example, a floor assembly, located in an indoor environment once the building is completed, does not need a water-resistive membrane. But a thin and robust membrane, ideally highly vapour permeable (e.g., building paper), may be installed to serve as a protective membrane for construction. This membrane, if it is not self-adhesive, can be removed once the floor is sheltered or simply retained, particularly when concrete topping will be installed on the floor. For a roof, work can be co-ordinated to pre-install part of the selected roofing membranes, which is typically thick, heavy-duty, and has a very low vapour permeance. Such membrane will slow down drying and may have to be removed to accelerate drying once wetting occurs. It may not be easy to remove self-adhesive membranes under such circumstances. Roofs should always be built with positive slopes to drains or scuppers to carry away surface water and prevent ponding.

In a wet climate (e.g., rain, snow), a temporary roof may be installed to shelter the construction, for materials or assemblies which are highly susceptible to water uptake and are very slow in drying, or highly susceptible to staining and would require costly efforts for remedial treatments. Such weather protection is common in the repair and retrofit of existing buildings to maintain normal living conditions (see an example in Figure 11). It would be beneficial in new construction if the budget allows. Fixed tents, similar to those used in retrofits, are primarily used to protect roof and cladding installation to avoid construction delays in a rainy or snowy climate (Figures 10, 12). Movable tents, which are raised as each storey is built, have been used in large timber projects in Europe (see an example in Figure 13). Compared to a fixed tent, a movable roof will have more stringent structural and mechanical requirements and therefore will cost much more. The cost of installing a temporary roof for protection during construction may be offset by the prevention of time loss, increased construction efficiency, and the elimination of re-drying or remedial treatments after on-site wetting. Such a method should be compared with other protection means (e.g., pre-applying membranes) to identify the most effective and economical measure when necessary.

Figure 11 Weather protection during retrofit of a building in Vancouver

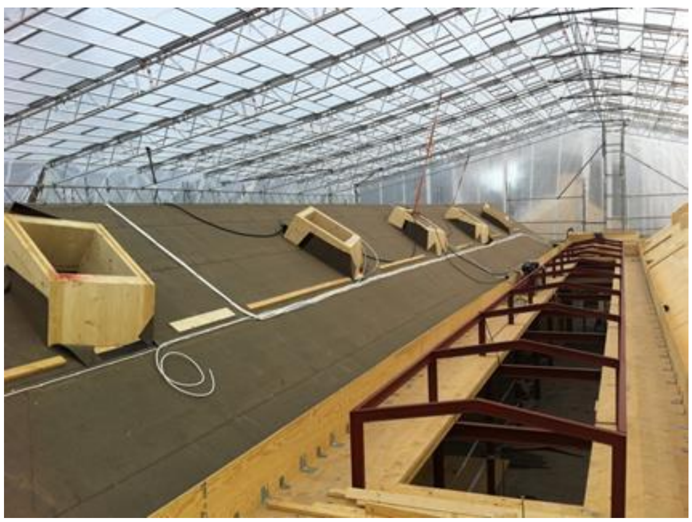

Figure 12 Using a tent to protect roof construction in Norway (Photo courtesy of Fristad Bygg)

Figure 13 Using a movable tent to protect the entire construction in Sweden

Prefabrication (***Groups D***) is strongly recommended for the construction of large and tall wood buildings since it typically reduces on-site exposure time and consequently wetting potential. The prefabrication plan, however, must be carefully reviewed to identify potential wetting risks. For prefabricated light wood framing (***Group D1***), some attention may be paid to components and joints that may trap moisture, such as the joints between bottom plates and subflooring (therefore standing water on subflooring should be removed to reduce water entrapment). In most cases, protective or permanent membranes, which are strong enough to resist the wear and tear during construction, can be pre-installed for walls or roofs to increase productivity and to provide extra protection to the inside framing during construction. The joints between membranes and with other materials should be immediately sealed upon installation to prevent water penetration. Sufficient attention should also be paid during the design of assemblies (e.g., the design of various joints) and factory assembling to facilitate on-site installation and to prevent any rain ingress during transportation and construction. This is particularly important for modular home installation when all materials are prefabricated into the assemblies (***Group D3***). Wetting also causes damage to finishing materials consequently requiring costly remediation efforts.

The shell of a building often provides the most effective and economical shelter for the wood inside and should be taken full advantage of during construction. This typically requires good sequencing and other considerations during construction. For example, an upper floor or a roof usually provides good protection to the floors and assemblies below, particularly when the joints and gaps are sealed (e.g., by using tongue and groove joints, or tape) after the installation. Any standing water (or snow) should be removed from floors after large precipitation events. When the wood is dry enough, install roof sheathing and waterproofing membrane, and exterior wall weather resistive barrier as quickly as the construction permits. The membranes should be sealed and made continuous at interfaces to prevent water penetration. Large openings in the roof and exterior walls, such as windows and doors, should be temporarily covered with translucent membranes (for providing natural light) to prevent blown-in rain (or snow) before final installation. Sufficient time should be provided for the wood members to dry and settle. Wet construction, such as concrete elevator shafts and concrete topping on subflooring (or on a roof), should be scheduled for completion at early stages to minimize any adverse impacts on the wood. When a roof built with mass timbers is exposed to rain, measures should be taken to dry them before installing any insulation or water proofing membrane above. It is difficult and slow for moisture to move through a mass timber component and to dry towards the interior once roofing is installed above. Walls, roofs, and any other parts must not be enclosed and finished until the framing materials have dried to an acceptable level of moisture, i.e., typically below 19% for wood. Insulation materials and membranes, spray foam and self-adhesive membranes in particular, should not be applied on wet wood. Mechanical methods, such as space heating, dehumidification, and forced ventilation, may be used to accelerate drying before and after enclosure. However, heating by using fuels, such as natural gas or propane, will add to the wetting load due to the extra moisture generated during burning of the fuel and may also become a construction fire concern.

5 CONCLUDING REMARKS

Different materials/assemblies require different levels of on-site protection to minimize water absorption and entrapment and to accelerate drying when wetting occurs. The amount of effort and the effectiveness of the methods depend on the climate, the types of assemblies involved, and other conditions, such as the construction method. As the last line of defense, building assemblies should always be designed to dry, in case wetting occurs during construction or in service.

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7 REFERENCES

ASTM (American Society for Testing and Materials). 2013. ASTM Standard D7438 – 13: Standard Practice for Field Calibration and Application of Hand-Held Moisture Meters. West Conshohocken, Pennsylvania, USA.

BRANZ. 2004. Preventing Construction Moisture Problems in New Buildings. BRANZ Bulletin, Number 447. Porirua City, New Zealand.

CWC (Canadian Wood Council). 2004. Managing Moisture and Wood. Building Performance Series, No. 6. Ottawa, Canada.

CWC (Canadian Wood Council). 2005. Introduction to Wood Design. Ottawa, Canada.

FII (Forestry Innovation Investment) and BSLC (Binational Softwood Lumber Council). 2014. Summary Report: Survey of International Tall Wood Buildings. Available on website: http://www.rethinkwood.com/tall-wood-survey (last accessed September 10, 2014).

Finch, G., J. Wang, and D. Ricketts. 2013. Guide for Designing Energy Efficient Building Enclosures for Wood-Frame Multi-Unit Residential Buildings in Marine to Cold Climate Zones in North America. FPInnovations Special Publication SP-53. FPInnovations, Vancouver, Canada.

Finnish Standards Association. 2012. SFS 5978 Execution of timber structures, Rules for load-bearing structures of buildings. Finnish Standards Association, Confederation of Finnish Construction Industries, RT, Finland.

Forintek Canada Corp. 2001. Guidelines for on-site measurement of moisture in wood building materials. Forintek report submitted to the Canada Mortgage and Housing Corporation and the Canadian Wood Council.

FPL (Forest Products Laboratory). 2010. Wood Handbook—Wood as an Engineering Material. General Technical Report FPL-GTR-113, U.S. Department of Agriculture, Forest Service, Madison, WI.

Fredriksson, M., L. Wadso, P. Johansson. 2013. The influence of microclimate on the moisture conditions on a Norway spruce joint exposed to artificial rain. Proceedings of the International Research group (IRG) annual meeting, IRG/WP 13-20505. IRG Secretariat, Stockholm, Sweden.

Garrahan, P. 1988. Moisture meter correction factors. Forintek Canada Corp. Proceedings of a seminar on “In-grade Testing of Structural Lumber”, held at USDA Forest Products Laboratory, Madison, WI.

Garrahan, P., J. Meil, and D.M. Onysko. 1991. Moisture in framing lumber: Field measurement, acceptability and use surveys. Forintek Canada Corp. report to Canada Mortgage and Housing Corporation.

HPO (Homeowner Protection Office). 2011. Building Enclosure Design Guide–Wood Frame Multi-Unit Residential Buildings. Homeowner Protection Office, Branch of BC Housing, Vancouver, Canada.

James, W.L. 1988. Electric moisture meters for wood. Gen. Tech. Rep. FPL-GTR-6. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. Madison, WI.

Kumaran, M.K. 2002. A thermal and moisture property database for common building and insulation materials. A final report from ASHRAE Research Project 1018-RP.

McClung, R., H. Ge, J. Straube, and J. Wang. 2014. Hygrothermal performance of cross-laminated timber wall assemblies with built-in moisture: field measurements and simulations. Building and Environment 71: 95-110.

McFarling A.M., A. Byrne, P.I. Morris. 2006. Characterizing the permeability of beetle-killed wood. Proceedings of the Canadian Wood Preservation Association. p27.

Morris, P.I. 1991. Effect of treating schedule on double-density incised spruce-pine-fir. Forest Products Journal 41(6): 43–46.

Morris, P.I. 1998. Understanding deterioration of wood in structures. Forintek report to British Columbia Building Envelope Council. Vancouver, BC, Canada. 29 p.

Nielsen, K.F., G. Holm, L.P. Uttrup, P.A. Nielsen. 2004. Mould growth on building materials under low water activities. Influence of humidity and temperature on fungal growth and secondary metabolism. International Biodeterioration & Biodegradation.54: 325-336.

Onysko, D., C. Schumacher, and P. Garrahan. 2010. Field measurement of moisture in building materials and assessments: pitfalls and error assessment. Proceedings of the BEST 2 Conference. April 12-14. Portland, OR 97204, US.

Scheffer, T.C. 1971. A climate index for estimating potential for decay in wood structures above ground. Forest Products Journal 21(10): 25-31.

Wang, J., J. Clark, P. Symons, and P.I. Morris. 2010. Time to initiation of decay in plywood, OSB and solid wood under critical moisture conditions. Proceedings of the International Conference on Building Envelope Systems and Technologies (ICBEST 2010), Volume 2 of 2, pp. 159-166, A. Baskaran, ed. National Research Council of Canada, Institute for Research in Construction. Ottawa, ON, Canada.

Wang, J., C. Ni, and G. Mustapha. 2013. Monitoring of vertical movement in a 4-story wood frame building in Coastal British Columbia. Journal of Testing and Evaluation 41(4): 611-618.

Wang, J. 2014. Phase I: Drying performance of experimental wood roof assemblies. FPInnovations report to the Canadian Forest Service, Natural Resources Canada.

Wang, J. and Ni, C. 2014. Monitoring of vertical movement in a 5-storey wood frame building in Coastal British Columbia. Proceedings of the World Conference on Timber Engineering, Quebec City, Canada, August 10-14, 2014.

Winter, S. 2014. “Nearly” high-rise timber buildings in Germany - Projects, experiences and further development. Proceedings of the World Conference on Timber Engineering, Quebec City, Canada, August 10-14, 2014.

APPENDIX I: CHECKLIST FOR AN EARLY DESIGN STAGE

The following list of items should be checked for major materials and assemblies used for a large/tall building in the design phase. See the document for detailed information.

1. Is the building going to be built in a climate that rarely rains or snows?

   - ☐ Yes. No need to proceed to the following check points
   - ☐ No. Proceed to the next item

2. What are the major wood materials or built-up assemblies used? Check the document for their wetting, drying, and appearance deterioration potentials.

   - ☐ Group A1: Dimension lumber
   - ☐ Group A2: Solid-sawn timbers
   - ☐ Group B1: Glued-laminated timber (glulam)
   - ☐ Group B2: Cross-laminated timber (CLT)
   - ☐ Group C1: Traditional sheathing panels, such as plywood, oriented strand board (OSB), and fiberboard
   - ☐ Group C2: Large structural composite products, such as parallel strand lumber (PSL), laminated strand lumber (LSL), oriented strand lumber (OSL), and laminated veneer lumber (LVL)
   - ☐ Group D1: Prefabricated light wood framing primarily using dimension lumber and sheathing panels
   - ☐ Group D2: Large nail-laminated members built with lumber and plywood
   - ☐ Group D3: Prefabricated closed assemblies, i.e., modular home assemblies
   - ☐ Other

3. If at least one of the following items is checked, extra on-site protection should be considered, in addition to careful design to achieve good drying performance and to prevent wetting in service.

   - ☐ The material or assembly absorbs water readily
   - ☐ The material or joints/interfaces allow water to get in and trap moisture
   - ☐ The material or assembly dries slowly once wetted
   - ☐ The material or assembly, such as a roof deck, will be enclosed with material (e.g., membrane, insulation) with low vapour permeance
   - ☐ Exposure to wetting during construction will require remediation treatments, such as removing staining on appearance products

4. Options for extra on-site protection measures and cost estimation, by working with the construction company.

   - ☐ Sealing all wood surfaces, particularly end grains, by using a water repellent or a primer; cost assessed
   - ☐ Purposely utilizing building shells for protection; cost assessed
   - ☐ Pre-installing protective membrane on a member or on an assembly; cost assessed
   - ☐ Using a fixed tent for partial protection of construction; cost assessed
   - ☐ Using a movable protective roof which rises during construction; cost assessed

5. Specify a suitable protection strategy and methods to protect wood during construction.

APPENDIX II: CHECKLIST FOR THE CONSTRUCTION STAGE

The following list of items should be checked for each major construction procedure of a large/tall wood building project, in coordination with the design team and other trades involved.

1. Is the construction happening in a dry climate that rarely rains or snows?

   - ☐ Yes. No need to proceed to the following check points
   - ☐ No. Proceed to the next item

2. What are the major wood materials or built-up assemblies used? Check the document for their wetting, drying, and appearance deterioration potentials.

   - ☐ Group A1: Dimension lumber
   - ☐ Group A2: Solid-sawn timbers
   - ☐ Group B1: Glued-laminated Timber (glulam)
   - ☐ Group B2: Cross-laminated Timber (CLT)
   - ☐ Group C1: Traditional sheathing panels, such as plywood, oriented strand board (OSB), and fiberboard
   - ☐ Group C2: Large structural composite products, such as parallel strand lumber (PSL), laminated strand lumber (LSL), oriented strand lumber (OSL), and laminated veneer lumber (LVL)
   - ☐ Group D1: Prefabricated light wood framing primarily using dimension lumber and sheathing panels
   - ☐ Group D2: Large nail-laminated members built with lumber and plywood
   - ☐ Group D3: Prefabricated closed assemblies, i.e., modular home assemblies

3. Does the material arrive on site with good wraps?

   - ☐ No. Carefully covering it with tarps and storing it in a well-ventilated shelter. Check the stored material regularly for any wetting incidents.
   - ☐ Yes. Avoiding damage to the wraps or moisture entrapment inside the wraps. Check stored material regularly for any wetting incidents.

4. Is the material or assembly in contact with the ground?

   - ☐ Yes. Place the material or assembly on dunnage
   - ☐ No. Proceed to the next item

5. Extra attention to site protection is required, if at least one of the following items is checked.

   - ☐ The material or assembly absorbs water readily
   - ☐ The material or joints/interfaces allow water to get in and trap moisture
   - ☐ The material or assembly dries slowly once wetted
   - ☐ The material or assembly, such as a roof deck, will be enclosed with material (e.g., membrane, insulation) with low vapour permeance
   - ☐ Exposure to wetting during construction will require remediation, such as due to staining on appearance products

6. Assess options for extra on-site protection measures by working with the team.

   - ☐ Sealing wood surfaces, particularly end grains, by using a water repellent or a primer; cost assessed
   - ☐ Purposely utilizing building shells for protection; cost assessed
   - ☐ Pre-installing protective membrane on a member or on an assembly; cost assessed
   - ☐ Using a fixed tent for partial protection of construction; cost assessed
   - ☐ Using a movable protective roof which rises during construction; cost assessed

7. Is wood moisture content measured during construction?

   - ☐ Yes. Provide drying measures, such as space heating and forced ventilation, before enclosure, if the moisture content readings are repeatedly above 20%
   - ☐ No. Monitor wood MC at critical locations. Provide drying measures when needed.

8. Implement effective and cost-effective on-site protection methods.