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Wood Information Sheet
WIS 4-14
Subject: Timber – general
Revised: December 2011

Moisture in timber

One of the most important factors affecting the performance and properties of wood is its moisture content. The amount of water present in wood can affect its weight, strength, workability, susceptibility to biological attack and dimensional stability in a particular end use.

We estimate that over 80% of the in-service problems associated with wood are in some way related to its moisture content. The importance of the interaction between water and wood cannot be understated and, if not properly understood and taken into consideration, can result in the need for expensive remedial measures.

This Wood Information Sheet (WIS) provides basic information for the specifier and user on the facts and importance of the moisture content of wood. Other WISs deal with specific uses of timber and advise on the specification of moisture content for those uses.

This WIS is an overview of the subject with signposts to more detailed sources that are listed at the end.

Contents

Figure 1: Cupping in a timber floor caused by a differential in moisture content between upper and lower faces

Key points

- The amount of water contained in a piece of timber is known as its 'moisture content' (mc).
- Up to 25%–30% moisture content the water in wood is chemically bound to the wood fibres. When the cell cavities are empty but the cell walls still retain all their bound water, the wood is said to be at 'fibre saturation point' (fsp).
- As mc continues to fall below fsp, the bound water is lost from the wood fibres, causing the wood to shrink laterally.
- Timber below approximately 20% moisture content is not considered to be risk from fungal decay.
- As it loses water below the 25%–30% fibre saturation point it will shrink laterally. Timber does not shrink or swell lengthwise along the grain.
- In constant conditions of temperature and relative humidity, timber will eventually reach a constant moisture content – the 'equilibrium moisture content' (emc).
- 'Movement' is the term for dimensional change that results from changes in emc that occur after the initial shrinkage has taken place. Movement occurs because, in practice, a stable emc is never reached.
- The most common moisture meters are electrical resistance meters. These work on the principle that, as the moistre content of a piece of timber increases, its electrical resistance decreases and vice versa.

Water and wood

WIS 2/3-28: Introducing Wood [1] explains the nomenclature and structure of wood, its conversion from the tree to logs and to sawn timber, and the characteristics that specifiers need to understand.

Living trees and freshly felled logs contain a considerable amount of water. It is an essential chemical constituent of the wood, not simply a remnant from water conduction in the tree. The amount of water contained in a piece of timber is known as its 'moisture content' (mc), expressed as a percentage of the oven dry weight of the wood:

$$\text{mc\%} = \frac{\text{weight of wet wood} - \text{weight of dry wood}}{\text{weight of dry wood}} \times 100$$

Thus a piece of wet timber whose weight is half dry wood and half water has a moisture content of 100%. Sometimes the weight of the water in a piece of wood exceeds the weight of the dry wood, in which case the moisture content exceeds 100%.

Up to 25%–30% moisture content the water in wood is chemically bound to the wood fibres. However, above this level, water fills or partially fills the cavities of the wood cells (fibres). When wood dries, this unbound water is lost first. This reduces the weight of the piece but does not change its dimensions. When the cell cavities are empty but the cell walls still retain all their bound water, the wood is said to be at 'fibre saturation point' (fsp), which is 25%–30% for most species. As mc continues to fall below fsp, the bound water is lost from the wood fibres, causing the wood to shrink.

Figure 2 shows the effect of drying from the saturated 'cavity full' condition, through the fsp to below fsp where the wood shrinks as the walls of the fibres contract. The process happens in reverse if dried wood is put into a wet or moist environment and it absorbs water.

Reasons for drying timber

It is usually necessary to dry wood before it is used or processed, unless it is going to be in water or in a very wet environment where its moisture content would remain above fsp. The main reasons for drying timber are to:

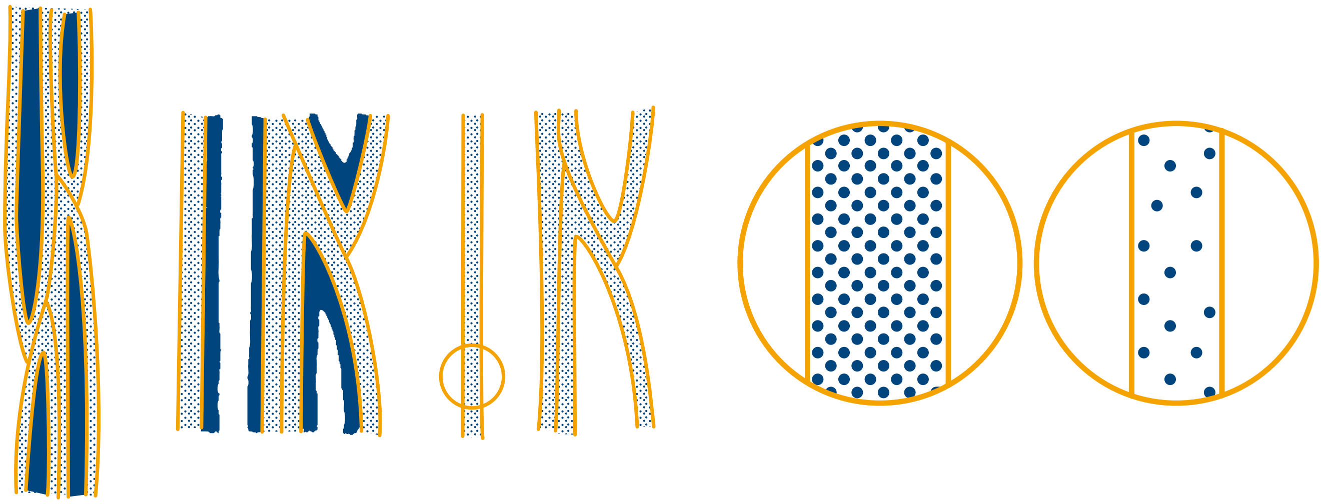
- avoid decay
- avoid shrinkage in service.

Further reasons for drying include:

- save weight during transportation
- facilitate machining
- enable strong glue joints to be made
- allow preservatives to penetrate
- increase the loads that timber can carry.

Avoiding decay

Many species of wood decay if kept at high moisture contents for long periods. Some susceptible timbers suffer from surface mould growth or staining even if they are kept wet for only a short time. Timber below approximately 20% moisture content is not considered to be at risk from fungal decay. However, surface mould growth and staining can occur at 18% moisture content under certain conditions.



Saturated wood: cavities full of water

Above 25–30% mc: cell cavities still contain some water

At fsp: cell cavities empty; cell walls contain bound water

Below fsp: cell walls lose bound water and shrink

Figure 2: What happens as wood dries

Avoiding shrinkage in service

Wet wood will usually dry out in service. As it loses water below the 25%–30% fibre saturation point it will shrink laterally. As well as reducing its cross-sectional dimension, distortion may occur if the grain of the piece is not straight. Pre-drying the wood allows these inevitable dimensional changes to be avoided in service and enables the production of accurately shaped and sized components.

Principles of timber drying

There are two main methods of drying timber – air drying and kiln drying. Traditionally timber was dried by stacking it and allowing it to air-dry naturally over many months or even years. Nowadays, timber is usually kiln-dried because this is quicker and more cost effective than air-drying. The terms 'air-dried' or 'kiln-dried' refer only to the process used and do not infer any specific moisture content value of the timber, unless this is quoted.

The process of commercial timber drying involves evaporating moisture from the surface of the wood. When timber is heated in a kiln the surface layers dry by evaporation, which results in the formation of a moisture gradient through the cross section of the piece between the drier surface layers and the 'wet' central core. This gradient causes the moisture in the 'wet' core to be drawn to the surface where it is lost through evaporation, thereby maintaining the moisture gradient until the timber is uniformly 'dry'. Therefore, while drying is occurring it is difficult to define precisely what the moisture content of a piece of wood is, since this will vary through the section.

Timber drying is a relatively slow process, which may take several days to several months, depending on the species of timber, its thickness and the drying facilities used. Drying is more rapid from the ends of boards or logs, unless they have been treated with an end grain sealing treatment. Timber which is dried in a kiln is usually given a 'conditioning treatment' at the end of the process to even-out the distribution of moisture in the pieces. Failure to do so can cause problems if the timber is subsequently re-sawn.

For many end uses the distribution of moisture in a piece of timber can be as important as its average moisture content. Lengthwise sawing or deep machining of pieces that have steep moisture gradients will result in distortion. This may occur immediately, due to the release of stresses set up during rapid drying, or more slowly as the new surfaces dry out. Moisture gradients are less significant in pieces which were dried in the shape in which they are to be used.

Equilibrium moisture content (emc)

Timber is a 'hygroscopic material'. This means that its moisture content changes in response to the temperature and relative humidity of its surroundings. In constant conditions of temperature and relative humidity, the timber will eventually reach a constant moisture content – the 'equilibrium moisture content' (emc) for those conditions. In practice, such stability of conditions rarely occurs and therefore a true equilibrium moisture content is never reached.

The response of timber to changes in temperature and relative humidity is quite slow and tends to 'average out' minor fluctuations in conditions such as 24-hour variations in central heating. The exposed outer layers of timber respond more rapidly to changes than the inner sections of a piece. Protective or decorative coatings, such as paints, varnishes and exterior wood finishes, slow down the response to a degree roughly related to the thickness of the coating. However, they will not prevent the moisture content of the timber from changing.

It is possible to measure seasonal changes in the equilibrium moisture content of timber in buildings (rather than in terms of days or weeks); such seasonal variations of 3%–6% are not uncommon. The dimensional changes can be noticeable, such as the external timber door that fits well in summer but 'sticks' in winter.

The actual emc value, for a given combination of temperature and relative humidity, varies slightly between different species of timber and also depends on whether the wood had to gain or lose moisture to reach the equilibrium level. Wood-based boards, such as plywood, chipboard and MDF, often have lower emc values than the timbers from which they were made.

Figure 3 shows the average emc for solid timber in a range of temperature and relative humidity combinations.

Shrinkage

Water held in wood below its fibre saturation point is chemically bound to the cell walls of the wood. Shrinkage (or swelling) occurs when this 'bound water' is lost (or gained) from the wood.

For most practical purposes the following apply:

- Timber does not shrink or swell lengthwise along the grain.
- Shrinkage starts as the timber dries below approximately 30% moisture content.
- It shrinks almost twice as much across the width of a flat sawn board (sawn in a tangential direction – parallel with the growth rings) as it does across a quarter sawn board (sawn radially – at right angles to the growth rings).

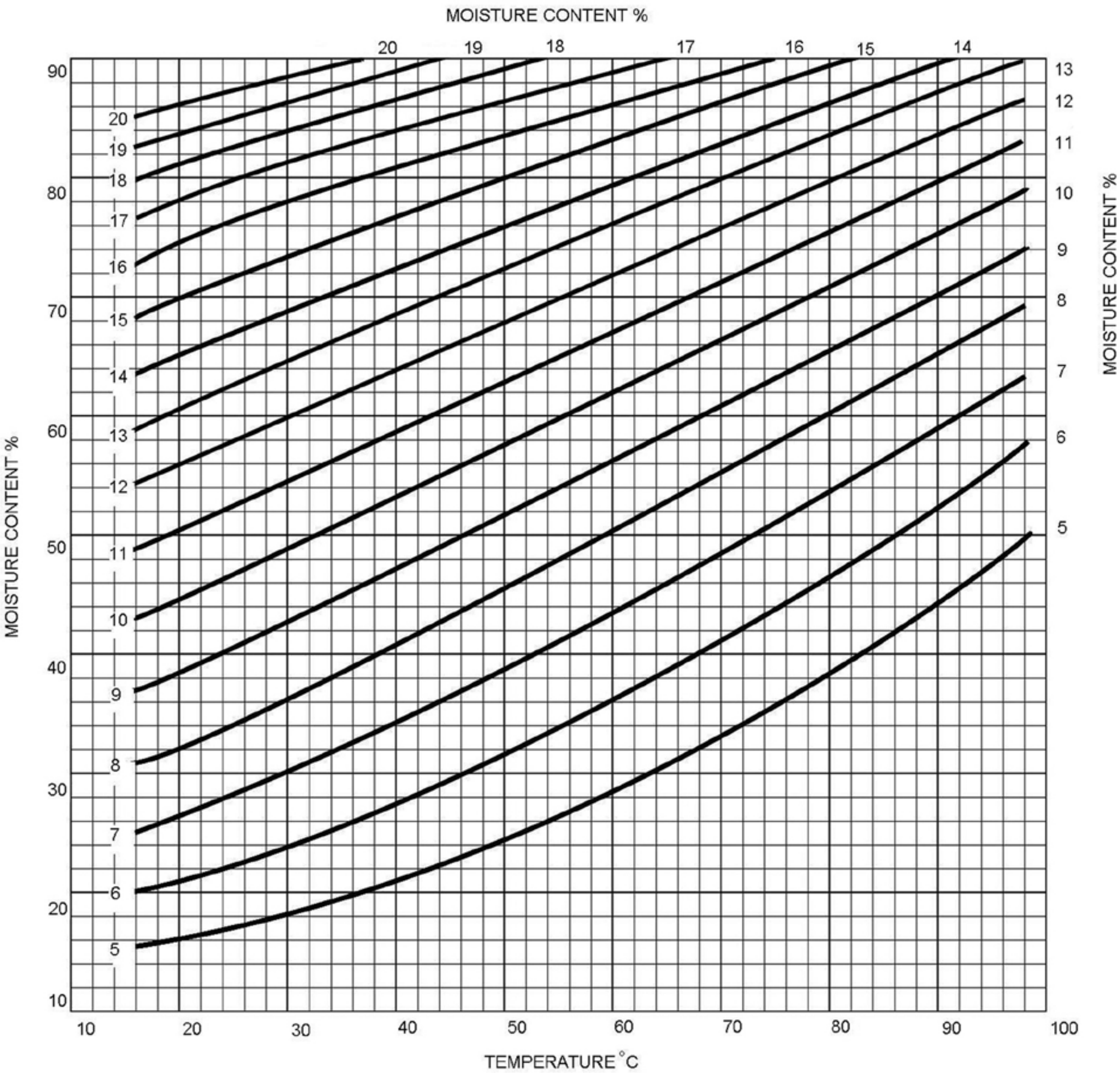


Figure 3: Average emc values of timber over a range of temperature and humidity
Data is based on average values obtained during drying from 'green' (wet) condition

- Tangential shrinkage or swelling is roughly 1% for every 3%–5% change in moisture content below 30% depending on the particular species in question; radial shrinkage is about half this.

If timber is put into service at a moisture content higher than that which it is likely to reach in time (higher than the likely emc), two interrelated problems can occur. One is shrinkage and the other is distortion.

With regard to shrinkage, if a piece of timber at 25% moisture content is put into a 16% emc environment, depending upon the species, it may be expected to shrink 3% tangentially and 1.5% radially. This may not seem much on a 25mm × 25mm batten but it represents 13mm on a 600mm deep laminated beam and 230mm on a 10m wide floor.

A severe mismatch, between the moisture content of timber at the time of supply, storage and/or installation and the emc it will settle to in service, can lead to serious problems such as excessive shrinkage and distortion.

Distortion is caused by the difference in the extent of shrinkage in a tangential direction compared with that radially along the length of a piece of timber for a given change in moisture content, coupled with the fact that the grain of a piece of timber is rarely perfectly straight. Thus, changes in moisture content below fsp can result in the bowing or twisting of studs, or the cupping of floor or cladding boards (*Figure 1*). Lower quality timber, which may contain a greater degree of angled grain and other defects, is more likely to distort than higher quality, straighter grained timber of the same species.

Careful design to accommodate anticipated shrinkage, coupled with sensible moisture content and timber quality specifications, will minimise such problems.

Movement

'Movement' is the term for dimensional change that results from changes in emc that occur after the initial shrinkage has taken place (generally when timber is in service). Movement occurs because, in practice, a stable emc is never reached. The magnitude of such a change is much lower than that for initial shrinkage but nevertheless it can be significant in certain timbers in particular end uses.

Table 1: Movement values of some common species

SMALL	MEDIUM	LARGE
abura	ash, American	beech, European
afzelia	ash, European	birch, American
agba	cherry, American	birch, European
cedar, S American	cherry, European	chestnut, sweet
Douglas fir	danta	Karri
gedu nohor	elm, European	keruing
guarea	elm, white	ramin
hemlock, Western	greenheart	rubberwood
idigbo	jarrah	
iroko	Kapur	
jelutong	Kempas	
lauan	maple, rock	
limba	maple, soft	
mahogany, African	Niangon	
mahogany, American	Nyatoh	
makoré	oak, American red	
mengkulang	oak, American white	
meranti	oak, European	
merbau	oak, Japanese	
obeche	pine, parana	
padauk	pine, radiate	
pine, Canadian red	pine, Scots	
pine, Corsican	poplar, American yellow tulipwood)	
pine, yellow	redwood, European	
purpleheart	Sapele	
rosewood	Utile	
sepetir	walnut, American	
spruce, Canadian	walnut, European	
spruce, Sitka	whitewood, European	
teak		
walnut, African		
Wengé		
Western red cedar		

Table 1 lists the propensity of various species to move. This classification is derived from the sum of the tangential and radial movements corresponding to a given change in humidity conditions from 90% to 60% at a constant temperature, and is expressed as a percentage:

- small: under 3%
- medium: 3%–4.5%
- large: over 4.5%.

Where movement tolerances are critical, such as for high quality joinery work or where temperature and relative humidity conditions are likely to vary considerably over a annual period, specify a timber with small movement characteristics. Consider also the conditions in a building when timber items are installed. Upon completion, a new building is likely to have a high relative humidity, which may cause joinery items to swell and subsequently shrink and possibly distort when the building dries. Avoid the practice of 'baking' buildings by 'speed drying' during the commissioning of heating systems.

Measuring moisture content

Control of wood moisture content, during processing and in use, is vital in order to avoid the development of moisture-related defects. There are two commonly used methods of measuring moisture content in wood – the oven dry method and the use of electrical moisture meters.

Oven dry method

The oven dry method (specified in *BS EN 13183-1: Moisture content of a piece of sawn timber. Determination by oven dry method* [2]) involves taking a sample of timber, weighing it to determine the mass of wood and water, drying it to obtain the mass of the wood, and then calculating the moisture content using the formula given on page 2.

This method has the advantage of providing an accurate assessment of the average moisture content of the samples tested but it is a destructive and time consuming test that does not identify moisture gradients within the sample piece. For these reasons its day-to-day use is largely confined to companies undertaking timber drying, where it is used for monitoring moisture content during the drying process, and to specialist applications where very accurate assessment of moisture content is necessary. TRADA Technology can provide guidance on this method of drying.

Moisture meters

Moisture meters are a quicker and more flexible method for measuring moisture content. Their main advantage is that they give instant readings that, although not necessarily highly accurate, can be repeated many times to give an overall picture of the moisture content in a piece/stack of timber. Most moisture meters are portable and/or handheld, so enabling them to be used to measure the moisture content of timber and timber products in a wide variety of situations and end uses.

The most common moisture meters are electrical resistance meters (specified in *BS EN 13183-2: Moisture content of a piece of sawn timber. Estimation by electrical resistance method* [3]), which work on the principle that, as the moisture content of a piece of timber increases, its electrical resistance decreases and vice-versa.

Electrical resistance meters measure the conductivity between two or more pin- or blade-like electrodes that are pushed or hammered into the timber and are calibrated to provide the user with a corresponding moisture content reading. Probes of different lengths may be provided for surface use, shallow penetration or deep hammer-assisted penetration. Probes with very short pins (1.5mm– 4mm in length) and surface probes or touch sensors are used for veneers. Standard probes normally consist of a pair of pins, approximately 10mm in length. These may be pressed into many timbers by hand.

For deeper penetration, probes with a sliding hammer provide the deepest penetration. These have pins of 25mm–45mm in length, with insulated shanks in order that only the moisture content of the timber in contact with the tips of the pins is measured. Screw probes are also available, for making moisture content estimates at depth and/or in very hard timbers. These are inserted into predrilled holes before being connected to the meter unit. It is generally recommended that, for most uses, probes should penetrate the wood to about one-third of its thickness, to get an approximation of average moisture content.

Another, less common type of meter is the capacitance type (specified in *BS EN 13183-3: Moisture content of a piece of sawn timber. Estimation by capacitance method* [4]). The difference is that capacitance-type meters give a measurement of the highest moisture content within the field penetration of the wood while electrical resistance meters provide a measurement of the moisture content of the wettest wood in contact with the bare parts of the probes (electrodes). This field of penetration may be up to 50mm in general purpose meters. The capacitance meter is suitable for use on decorative timbers as they cause no damage to the surface of the wood, unlike the probes of electrical resistance meters.

Factors affecting meter readings

Timber species

The timber species, from which readings are taken, has a significant effect on electrical resistance, owing to differences in the structure and constituents of the wood. A resistance meter may have scales or adjustment factors to cater for many common species.

Panel products

Readings in panel products should be regarded with caution, unless the meter manufacturer has produced calibration charts for the particular product being tested. In particular, plywoods using phenolic adhesives have been shown to give much higher readings than the actual oven-dry values, particularly at moisture contents of 15% and above. This is due to a chemical constituent in some glues of this type.

Treated or contaminated wood

Chemical treatment or contamination of wood may make the use of a meter so erratic as to be useless. The main causes of erroneous (generally higher) readings are:

- waterborne preservative treatments
- certain water-borne flame retardant treatments
- contamination by salt water.

If salt contamination is likely, treat moisture readings that are higher than expected with suspicion. Metallic paints, such as aluminium primers, are the only paints likely to affect readings. Creosote or organic solvent preservative treatment seem to have no significant effect.

Surface moisture

Surface moisture, due to wetting or condensation, can give a misleading reading of the overall moisture content of a piece of timber. In these conditions, take readings with insulated probes. Check to see that the insulation has not worn away and ensure that the retaining nuts for the pins do not come into contact with the wood surface, since this may also allow a ‘short circuit’ and give erroneous readings.

Temperature

Temperature has a significant but predictable effect on the electrical resistance of wood. Follow the instructions for the correction procedure, provided with resistance meters.

Accuracy

Electrical resistance moisture meters are most effective when used on timber with a moisture content of between 8% and 25%. In timber with moisture content of between 20% and 25%, a meter should give a reading within +/– 2%; in timber below

15% moisture content, the reading should be within +/– 1%. In situations where the moisture content reading is outside this range, consider the reading as indicative only. In timber with a moisture content of less than 8%, many electrical resistance meters will not provide a reading. Therefore, if the meter fails to provide a reading when used in a heated internal environment, this may indicate low timber moisture content rather than a potential fault with the meter. Capacitance meters are less accurate in general use (probably +/– 5%).

Good practices with moisture meters

Subject material

- Identify the species and determine adjustment factor/scale to be applied.
- Measure/estimate the temperature and determine/set the correction.
- Consult the manufacturer's guidance on composite materials.
- Consult the manufacturer's guidance on treated or contaminated material, or use an alternative method to determine moisture content.
- With painted material, check for metallic paint, which will give a high surface meter reading; readings with insulated probes should be unaffected.
- Do not rely on the accuracy of readings taken in wet timber (above fsp).

Probe

- Use the type of meter and probes appropriate to the depth at which readings are required and make sure the pins are well embedded and in firm contact with the wood.
- If the wood surface is damp, or a steep moisture content gradient is expected, use insulated probes, even for readings taken from near the surface.

Meter

- Check the battery according to instructions.
- Carry out zero and scale setting as instructed.
- Use a calibrator or check box (these should be available from the meter supplier) prior to using the meter to check its accuracy.

Procedure

- Use progressive penetration of insulated electrodes, with readings taken at intervals of penetration to determine a moisture gradient.
- When drying gradients are present, penetrate to a depth of between one-quarter and one-third of the timber thickness, to get an approximate average moisture content.
- Measure along or across the grain, according to the instructions for use of the particular meter. Do not expect an accurate reading of the average moisture content of a piece of timber by sticking the electrode into the end grain; the end of a piece is likely to be drier or wetter than the piece as a whole.

Reading

- Don't delay; take the reading after a few seconds. A longer delay may result in a reading which has crept downwards. Follow the manufacturer's guidance.

Maintenance / calibration

- Apart from using a calibrator or check box before making the readings, carry out checks or send the instrument for maintenance at agreed or recommended intervals.

Specifying moisture content

The reasons for specifying the moisture content of timber for a particular end use are to:

- minimize in-service problems due to dimensional changes or distortion – this category includes items such as furniture, joinery, flooring etc
- enable efficient processing, such as preservative treatment, gluing, machining and fabrication
- prevent deterioration
- ensure adequate strength of the timber members.

Although many British and European Standards offer guidance on specifying moisture contents of timber and panel products, it remains the specifier's responsibility to agree with the client whether more, or less, stringent specifications are appropriate.

A specification of moisture content should include:

1. the average moisture content of the batch
2. the tolerance limits on the average moisture content of individual pieces within that batch, for example "The average moisture content of the timber in the batch will be 20%, with no individual reading over 24%."
3. a limitation on the variability of moisture content within the individual pieces, either at different depths (moisture gradients) or at different positions along the length, or both
4. the method of measurement.

While the appropriate standard will usually give the information necessary to specify item 1, specification items 2 and 3 will depend on the end use and whether variation from piece to piece or within individual pieces is critical.

There are two key standards that give general guidance on moisture contents for timber to be installed in buildings – *Eurocode 5* [5] for structural timber and *BS EN 942: Timber in joinery. General requirements* [6] for joinery.

Table 2: Service classes specified in Eurocode 5

Service Class		End use examples	Average in-service moisture content
1	Characterised by a moisture content corresponding to a temperature of 20°C and relative humidity of surrounding air exceeding 65% for a few weeks each year	Internal uses in continuously heated buildings	In most softwood will not exceed 12%
2	Characterised by a moisture content corresponding to a temperature of 20°C and relative humidity of surrounding air exceeding 85% for a few weeks each year	Covered and generally heated	Moist softwoods will not exceed 20%
		Covered and generally unheated	
3	Characterised by a moisture contents higher than those in Class 2	External uses, fully exposed	20% +

TRADA Technology recommends *Eurocode 5* for structural design of timber. The principal design criterion relating to moisture in timber is the service class. The services classes defined in *Eurocode 5* are the same as in *BS 5268-2 Structural use of timber. Code of practice for permissible stress design, materials and workmanship* [7]. *Table 2* summarises the service classes specified in *Eurocode 5*, together with the guidance moisture content likely to be attained in service.

Similarly, *Table 3* summarises the categories specified in *BS EN 942* for joinery, together with the moisture content likely to be attained in service. The Standard also advises that no single moisture content reading should exceed the maximum average value by 3%.

Table 3: Moisture content recommendations for joinery

BS EN 942 – Category	Sub-category based on in-service climates	Average moisture content in service
External Joinery	–	12%–19%
Internal Joinery	Unheated buildings	12%–16%
	Buildings with heating providing room temperatures of 12°C–21°C	9%–13%
	Buildings with heating providing room temperatures in excess of 21°C	6%–10%

BS 8201 Code of practice for installation of flooring of wood and wood-based panels [8] contains guidance on specifying the moisture content of timber flooring.

Care of dried timber

Follow *WIS 4-12: Care of timber and wood-based products on building sites* [9].

Once timber has been dried to a level appropriate to its end use, store it so that any moisture content changes are minimal. This will minimise the risk of movement in service. Wood, close piled under adequate cover, may be stored for a week or two without major changes in moisture content. However, softwoods and permeable hardwoods at low moisture content will take up moisture more quickly than some less permeable hardwoods.

Deliver and install flooring, joinery, furniture and any wood supplied at the lower moisture contents after the building has dried out and the temperature and relative humidity in the building are at the levels expected in service. Otherwise take precautions to limit the risk of moisture uptake by the timber, such as installing temporary heating and dehumidification equipment in a building and establishing a temporary storage facility for the timber.

References

1. WIS 2/3-28: *Introducing Wood*, TRADA Technology, 2003
2. BS EN 13183-1:2002 *Moisture content of a piece of sawn timber. Determination by oven dry method*, BSI
3. BS EN 13183-2:2002 *Moisture content of a piece of sawn timber. Estimation by electrical resistance method*, BSI
4. BS EN 13183-3:2005 *Moisture content of a piece of sawn timber. Estimation by capacitance method*, BSI
5. BS EN 1995-1-1:2004+A1:2008 *Eurocode 5. Design of timber structures. General. Common rules and rules for buildings*, BSI
6. BS EN 942:2007 *Timber in joinery. General requirements*, BSI
7. BS 5268-2:2002+A1:2007 *Structural use of timber. Code of practice for permissible stress design, materials and workmanship*, BSI
8. BS 8201:2011 *Code of practice for installation of flooring of wood and wood-based panels*, BSI
9. WIS 4-12: *Care of timber and wood-based products on building sites*, TRADA Technology, 2008

About TRADA

The Timber Research and Development Association (TRADA) is an internationally recognised centre of excellence on the specification and use of timber and wood products.

TRADA is a company limited by guarantee and not-for-profit membership-based organisation. TRADA's origins go back over 75 years and its name is synonymous with independence and authority. Its position in the industry is unique with a diverse membership encompassing companies and individuals from around the world and across the entire wood supply chain, from producers, merchants and manufacturers, to architects, engineers and end users.

Our aim

To provide members with the highest quality information on timber and wood products to enable them to maximise the benefits that timber can provide.

What we do

We seek to achieve this aim through active and on-going programmes of information and research. Information is provided through our website, an extensive collection of printed materials and our training courses.

Research is largely driven by the desire to update and improve our information so that it continues to meet our members' needs in the future.

TRADA Technology is contracted by the Timber Research and Development Association to prepare and publish all Wood Information Sheets.

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