TIMBERS DRYING TECHNIQUES

WOOD TECHNOLOGY

TRAINING MANUAL

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ABBREVIATION AND ACRONYMS

GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
RTB	Rwanda TVET Board
RP	Rwanda Polytechnic
RH	Relative humidity
T	Temperature
DG	Drying Gradient
MC	Moisture Content
EMC	Equilibrium Moisture Content
TMT	Thermally Modified Timber
L	Length in meter
W	Width in meter
Th	Thickness in meter
SDS	Safety Data Sheet
DUS	Draft Ugandan Standard
CCA	Chromated Copper Arsenate
ISPM 15	International Standards for Phytosanitary Measures no. 15
FPL	Fireplace
FAS	Firsts and Seconds

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LEARNING UNIT 1: DESCRIBE WOOD PROPERTIES

1.1 Wood chemical properties affecting wood drying process

1.1.1 Cellulose

Cellulose is the most important single material produced by plants, constituting 1/3 of all materials produced. In wood nearly half the dry weight is made up of cellulose.

It is believed that the cellulose molecules are identical from all sources such as wood, cotton, flax, ramie, straw, bamboo etc. Cellulose is a long chain polymer of several thousand glucose residues. Cellulose is highly hygroscopic but is not soluble in water, partly due to its regularity and partly due to the large number of hydrogen bonds. Aqueous alkalis will swell cellulose and degrade it, but not dissolve it. Cellulose can be dissolved by aqueous cuprammonium hydroxide and Cadmium triethylenediamine.

Strong acids like 72 % Sulphuric acid or 41 % hydrochloric acid will dissolve cellulose, but at the same time rapidly degrade it. The hemicelluloses constitute that portion of the polysaccharides which is soluble in dilute alkali. Is the most abundant substance in the world. It forms the skeleton of cells. In softwoods: 46-55%, in hardwoods: 41-48%. The basic unit: anhydro-d-Glucopyranose residues Degree of polymerization: 5,000-14,000.

Cellulose is a long chain polymer of several thousand glucose residues. $(C_6H_{10}O_5)_n$ Higher amount of crystalline form results in:

Higher wood density, Higher modulus of elasticity (MOE), Higher strength in tension, Lower shrinkage /swelling. The long cellulose molecules are aligned in parallel to form bundles called elementary fibrils. These are again aggregated into ribbon like bands named micro fibrils.

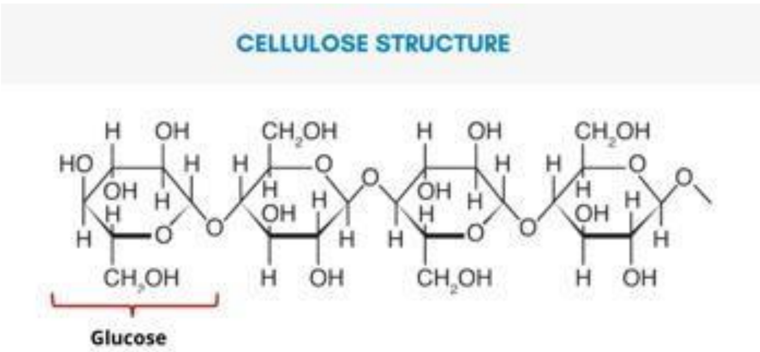


Figure 1: Cellulose structure

Exercise:
What are the roles of Cellulose in wood?

1.1.2 Hemicellulose

The hemicelluloses constitute that portion of the polysaccharides which is soluble in dilute alkali. Hemicelluloses (Polyoses) = a mixture of other polysaccharides in wood.

Heteropolymers: more than one type of basic unit (monomer). Hemicelluloses, the second important constituent of wood, are also sugar polymers. Unlike cellulose, which is made only from glucose, hemicelluloses consist of glucose and several other water-soluble sugars produced during photosynthesis. In hemicelluloses the degree of polymerization is lower – they are composed of shorter molecules than cellulose. Degree of polymerization: 100-200.

They make up 20–35% of the dry weight of wood. There are many varieties of hemicelluloses and they markedly differ in composition in softwoods and hardwoods. Generally, hemicelluloses are in a relatively greater proportion in hardwoods than in softwoods. Hemicellulose is a general term for a group of complex polysaccharides in plant cell walls; it is the second largest category of plant cell wall polysaccharides, and mainly exists in the primary walls and secondary walls of the plant cell walls. The structure of hemicellulose is complicated, and is primarily composed of several different types of pentoses (β-d-xylose, α-l-arabinose), hexoses (β-d-glucose, β-d-mannose, α-dgalactose, α-l-rhamnose, and α-l-fucose), and glycolytic acid (α-d-glucose fermentation acid, α-d-4-O-methyl-glucose acid, and α-d-galacturonic acid). The molecular weight of hemicellulose is lower than that of cellulose.

Glucomanans: is a water-soluble polysaccharide that is considered a dietary fiber. It is a hemicellulose component in the cell walls of some plant species. Glucomanan is a food additive used as an emulsifier and thickener. Main units: hexoses, D.P.60-70 Softwoods) up to 20%), hardwoods (3-5%). Galactans: Galactans found in red seaweeds and are commercially important due to their extensive usage as gelling and thickening agents in the food industry because of their rheological properties. These galactans based on their stereochemistry are basically classified as agarans and carrageenans. Agarans are galactans with 4-linked α-galactose residues. Low content amount in pine, beech, birch: 0.5-3%, higher content amount in compression wood.

1.1.3 Lignin

Lignin is a colorless and completely amorphous substance with the basic structure of a phenol ring. Lignin is the second most abundant renewable biopolymer found in nature, with cellulose being the most abundant. It is a relative complex compound having a cross-linked phenolic type structure which does not easily breakdown. Due to its aromatic structure, it is more chemically stable and heat resistant than cellulose. Lignification of the cell wall takes place during the final stages of secondary wall formation when lignin coat the cell wall and gives it rigidity and toughness. Lignin can be dissolved directly from wood with formic or acetic acid. Commercially, lignin is removed from wood by different pulping processes. Lignin is insoluble in water and very low in hygroscopicity.

The most important features of lignin are: The toughness it imparts/communicates to the cell walls, its low hygroscopicity which reduces the dimensional changes in wood following changes in moisture content. It is thermoplastic in its natural state in wood, a property that is utilized in bonding of certain types of fibre and particleboards. In addition to the variation in composition of the hardwoods shown, a further variation is that tropical hardwoods in general have a higher lignin content than the hardwoods from temperate zones, often more than many softwoods. Lignin affects wood properties:

- Improves wood stiffness
- -It improves wood strength properties (compression, bending)
- It improves wood resistance to fungi
- It lowers wood permeability for water

	Softwood (%)	Hardwood (%)
Cellulose	40 -50	40 - 50
Hemicellulose	20 -35	20 - 40
Lignin	25 -35	20 - 30
Pectin, starch, ash	1 - 4	1 - 4

Lignin is of vital importance as a structural material in wood and can account for up to 40 % of the dry biomass. It is basically the aromatic part of the wood "composite" that acts like an adhesive in plant cell walls and provides rigidity to the wood. It also prevents rapid break down of the cellulosic material since it is mostly found between cells, but also within the cells itself.

Exercise:
1. What are proportion of lignin n soft wood versus to hardwood 2. What are the roles of lignin on wood properties?

1.1.4 Wood extractive

Wood extractives are natural products extraneous to a lignocellulose cell wall. They are present within a cell wall, but are not chemically attached to it. Wood extractives are substances which may be coated in the cell walls or which are deposited inside the cell lumen.

They represent a very large number of organic compounds, often very complex in structure, and the most important are the polyphenols and the wood resins. Extractives: compounds which can be extracted from wood by standard methods and they are divided into cold and hot water extractives, alcohol extractives, benzene extractives etc.

Their amounts vary considerably, normally extractives make up less than 5 % of the dry weight of the wood but the heartwood of certain species has been found to contain more than 40 % extractives.

Important extractives are the wood resins which are the source of wood turpentine, tar oil and rosin (is now as ester gum is oil soluble food additive, is used as an ingredient in production of ice cream). Other extractives are pinosylvin (is fungi toxin) responsible for the high natural durability of pine.

Pinosylvin is further responsible for preventing pine heartwood from being digested in sulphite pulping. The tannins form another group of commercially important extractives, and amount of 20 – 25 % on a weight basis have been found in *Schinopsis lorentzii*.

Gum from Acacia spp is another important extractive, even though it is obtained by beating living trees and not by extraction from wood. Heartwood extractives in many species impregnate/soak the cell wall to the extent that water movement is restricted, thus reducing the shrinking and swelling of the wood.

Extractives further give wood colour and odor and influence its permeability and physical properties such as basic density, hardness and compressive strength. Flammability is very much a function of resin content. Some extractives are valuable drugs such as quinine, while others are allergic or actually highly toxic.

Some extractives inhibit the setting of glues which affects the use of wood in concrete forms. Some extractive will accelerate the corrosion/rust of metal in contact with wood.

The paintability of wood can be adversely affected by extractives, resulting in poor adhesion or staining.

Some extractives may cause colored point in the pulp, discoloration and other result in sticky/gummy deposits in the pulp and/or paper mill or in the paper sheet.

Heartwood consists of an inner core of wood cells that have changed, both chemically and physically, from the cells of the outer sapwood. The cell cavities of heartwood may also contain deposits of various materials that frequently give heartwood a much darker color.

Extractive deposits formed during the conversion of living sapwood to dead heartwood often make the heartwood of some species more durable in conditions that may induce decay.

Discoloration

Staining or discoloration of wood may result from chemical processes that convert originally colorless or light-colored, naturally occurring extractives into intensely colored products. Most of the so-called chemical stains result from oxidation of certain wood extractives by air during air seasoning or kiln drying. Colors observed include shades of brown, blue, green, yellow, and red. Affected species include both hardwoods (oak, birch, maple, alder, basswood, gum, etc.) and softwoods (pines, hemlock).

Exercise:
1. Localize extractive in wood 2. What are the importance of wood extractive?

1.1.5 Wood water

Water is an essential ingredient to life and as such is found throughout all living cells. In the tree, water is transported through the lumens of water transport cells 4 vessel cells 3 mm and it also saturates the cell walls giving rise to two classifications of water in wood.

- **Free water**

Free water: This liquid, present in the cell cavities/ cell lumens, just because its properties are very close to those of liquid water: density, viscosity, saturated vapor pressure. Liquid water found also other void spaces in wood. It is freely removed once a tree is cut down and the bound water need the external force to be removed in the wood.

When wood dries, most free water separates at a faster rate than bound water because of accessibility and the absence of secondary bonding. When wood dries, most free water separates at a faster rate than bound water because of accessibility and the absence of secondary bonding.

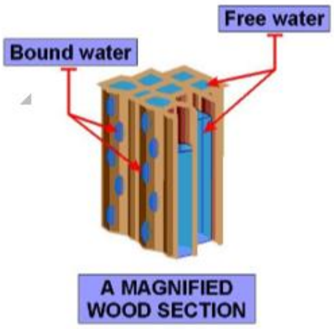
- **Bound water**

Bound water: Bound moisture is associated with the hygroscopic nature of the woody components.

There are some uncertainties about the limits of hygroscopic behavior, particularly with woods of high extractives content; but it is useful to define a maximum sorptive moisture content, called the fibre saturation point (FSP).

Bound water, it is bonded (via secondary or hydrogen bonds) within the wood cell walls. Water molecules that penetrate the cell walls and chemically bound to cellulose molecules. It is the removal of bound water that causes shrinking of wood. Bound water are held in cell walls.

As bound water, it is bonded (via hydrogen bonds) within the wood cell walls. In softwoods nearly all of the water is found as free water in the lumen or bound water within the cell wall of tracheid cells. In hardwoods, water is found in the cell walls of all the cell types but most of it is contained as free water within the lumens of the large vessel cells. The major portion of water transport in a living tree occurs in the outer sapwood, in the tracheid of softwoods and the vessels of hardwoods. The sapwood in conifers normally has a very high moisture content. In the heartwood zone of the tree, the cells are dead and no longer involved in water transport. The heartwood normally has a lower moisture content than sapwood in confers, however the moisture content of heartwood and sapwood are often very similar in hardwoods.



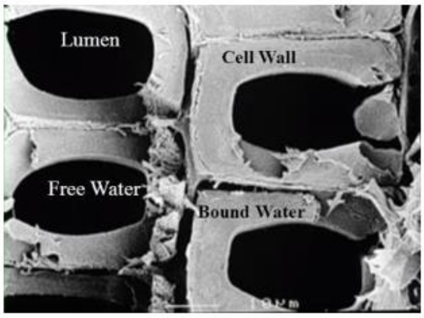


Figure 2: Water in wood cells

Bound water affects size of the wood and affects strength of the wood (spreading of microfibrilis in the cell wall). Harder to remove from wood that free water as H-bonded Wood (cell wall) is hygroscopic. Changes in relative humidity affect the amount water in wood. Increase RH, increase amount of bound water, increase the size of wood Decrease Rh, decrease amount of bound water, and decrease the size of the wood o Moisture content percent (% M.C) is used to quantify the amount of water in wood.

➢ Equilibrium moisture content

In use, the moisture content of a piece of wood will eventually reach equilibrium with the surrounding atmosphere. The moisture content of wood below the fiber saturation point is a function of both relative humidity and temperature of the surrounding air. Equilibrium moisture content (EMC) is defined as that moisture content at which the wood is neither gaining nor losing moisture; an equilibrium condition has been reached. The relationship between EMC, relative humidity, and temperature. Although the relationship between RH and moisture content is not linear, an increase in RH or a decrease in temperature will increase the predicted moisture content of wood, after its equilibration with the air (EMC).

The non-linear nature of the RH-EMC relationship is a typical sorption isotherm and has been described by sorption theory.

Temperature		Moisture content (%) at various relative humidity values																		
(°C	(°F))	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%
–1.1	(30)	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.4	13.5	14.9	16.5	18.5	21.0	24.3
4.4	(40)	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.3	13.5	14.9	16.5	18.5	21.0	24.3
10.0	(50)	1.4	2.6	3.6	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.3	11.2	12.3	13.4	14.8	16.4	18.4	20.9	24.3
15.6	(60)	1.3	2.5	3.6	4.6	5.4	6.2	7.0	7.8	8.6	9.4	10.2	11.1	12.1	13.3	14.6	16.2	18.2	20.7	24.1
21.1	(70)	1.3	2.5	3.5	4.5	5.4	6.2	6.9	7.7	8.5	9.2	10.1	11.0	12.0	13.1	14.4	16.0	17.9	20.5	23.9
26.7	(80)	1.3	2.4	3.5	4.4	5.3	6.1	6.8	7.6	8.3	9.1	9.9	10.8	11.7	12.9	14.2	15.7	17.7	20.2	23.6
32.2	(90)	1.2	2.3	3.4	4.3	5.1	5.9	6.7	7.4	8.1	8.9	9.7	10.5	11.5	12.6	13.9	15.4	17.3	19.8	23.3
37.8	(100)	1.2	2.3	3.3	4.2	5.0	5.8	6.5	7.2	7.9	8.7	9.5	10.3	11.2	12.3	13.6	15.1	17.0	19.5	22.9
43.3	(110)	1.1	2.2	3.2	4.0	4.9	5.6	6.3	7.0	7.7	8.4	9.2	10.0	11.0	12.0	13.2	14.7	16.6	19.1	22.4
48.9	(120)	1.1	2.1	3.0	3.9	4.7	5.4	6.1	6.8	7.5	8.2	8.9	9.7	10.6	11.7	12.9	14.4	16.2	18.6	22.0
54.4	(130)	1.0	2.0	2.9	3.7	4.5	5.2	5.9	6.6	7.2	7.9	8.7	9.4	10.3	11.3	12.5	14.0	15.8	18.2	21.5
60.0	(140)	0.9	1.9	2.8	3.6	4.3	5.0	5.7	6.3	7.0	7.7	8.4	9.1	10.0	11.0	12.1	13.6	15.3	17.7	21.0
65.6	(150)	0.9	1.8	2.6	3.4	4.1	4.8	5.5	6.1	6.7	7.4	8.1	8.8	9.7	10.6	11.8	13.1	14.9	17.2	20.4

Table 1: Moisture content of wood in equilibrium with stated temperature and relative humidity

Wood in service is exposed to both long-term (seasonal) and short-term (daily) changes in relative humidity and temperature of the surrounding air. Thus, wood is always undergoing at least slight changes in moisture content.

These changes usually are gradual, and short-term fluctuations tend to influence only the wood surface. Moisture content changes can be retarded, but not prevented, by protective coatings, such as varnish, lacquer, or paint.

The objective of wood drying is to bring the wood close to the moisture content a finished product will have in service.

➢ Sorption

The amount of water adsorbed from a dry condition to equilibrium with any relative humidity is always less than the amount retained in the process of drying from a wetter condition to equilibrium with that same relative humidity.

The ratio of adsorption EMC to desorption EMC is constant at about 0.85. Furthermore, EMC in the initial desorption (that is, from the original green condition of the tree) is always greater than in any subsequent desorption. Which is thought to represent a condition midway between adsorption and desorption and a suitable and practical compromise for use when the direction of sorption is not always known.

➢ Shrinkage

Wood is dimensionally stable when the moisture content is greater than the fiber saturation point. Wood changes dimension as it gains or loses moisture below that point.

It shrinks when losing moisture from the cell walls and swells when gaining moisture in the cell walls. This shrinking and swelling can result in warping, checking, splitting, and loosening. The moisture content at which the cell walls are still saturated but virtually no water exists in the cell cavities is called the fiber saturation point (FSP).

The fiber saturation point usually varies between 21 and 28%. Wood is a hygroscopic material that absorbs moisture in a humid environment and loses moisture in a dry environment.

Fiber saturation point: only water bound in the cell wall remains, all other water (free water), have been removed from the cell cavities/lumen.

Moisture content: The Moisture Content (M.C.) of a piece of timber is defined as the weight of water contained in the piece expressed as a percentage of its oven dry weight.

As a result, the moisture content of wood is a function of atmospheric conditions and depends on the relative humidity and temperature of the surrounding air. Location of water in wood cells during the drying process. At fiber saturation point (FSP), only the cell walls contain water.

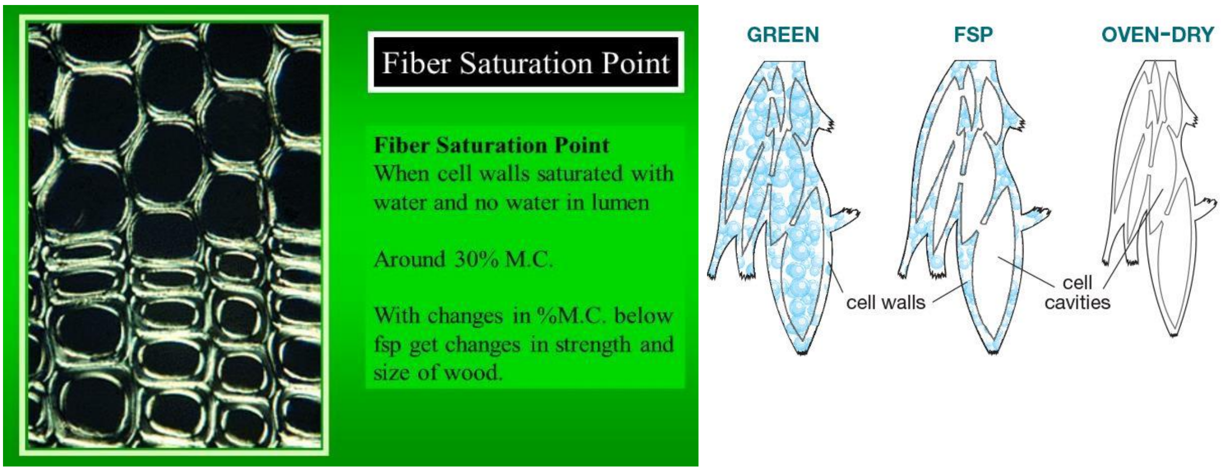
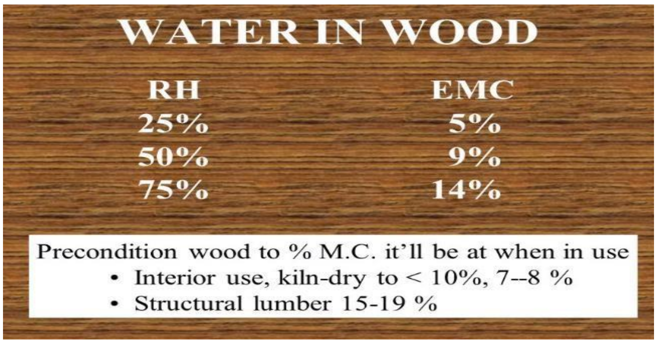


Figure 3: Fiber saturation point

The moisture content of wood is defined as the weight of water in wood given as a percentage of oven dry weight. In equation form, moisture content (MC). Dry wood in oven set at 105^{0}C

(220^0 F) until wood reaches constant weight. Weight, shrinkage, strength, and other properties depend upon the moisture content of wood.

$$\% \text{ M.C.} = \frac{\text{Original Wt. --- Oven-dry Wt.}}{\text{Oven-dry Wt. Of Wood}} \text{ X } 100\%$$



All wood in normal application will have water in it. Amount of water is proportional to the relative humidity. At a given relative humidity, wood reaches an Equilibrium Moisture Content (EMC).

In trees, moisture content can range from about 30% to more than 200% of the weight of wood substance. In softwoods, the moisture content of sapwood is usually greater than that of heartwood. In hardwoods, the difference in moisture content between heartwood and sapwood depends on the species.

Under constant conditions of temperature and humidity, wood reaches an equilibrium moisture content (EMC) at which it is neither gaining nor losing moisture.

The EMC represents a balance point where the wood is in equilibrium with its environment. The time required for wood to reach the EMC depends on the size and permeability of the member, the temperature, and the difference between the moisture content of the member and the EMC potential of that environment.

Above the fiber saturation point, wood will not shrink or swell from changes in moisture content because free water is found only in the cell cavity and is not associated within the cell walls. Wood changes in dimension as moisture content varies below the fiber saturation point.

Wood shrinks as it loses moisture below the fiber saturation point and swells as it gains moisture up to the fiber saturation point.

➢ How Water Moves Through Wood

The movement of fluids through wood is a complex phenomenon involving diffusion and pressure driven flow. Gases and vapors can move through the cell walls as well as the void spaces of the wood by the diffusion of molecules along a concentration gradient.

The uptake of water into wood is called sorption and the loss of water from wood is referred to as desorption or drying. Drying of wood with an MC greater than FSP involves both free water and bound water. Bound water movement through wood is an example of diffusion where the water molecules move from wetter wood to drier wood.

The molecules jump from cellulose molecule to cellulose molecule within the cell walls and between adjacent cell walls. Free water movement in wood occurs because liquids can move through an intricate pathway of interconnected capillaries of lumens and pits in response to a pressure gradient or surface tension forces.

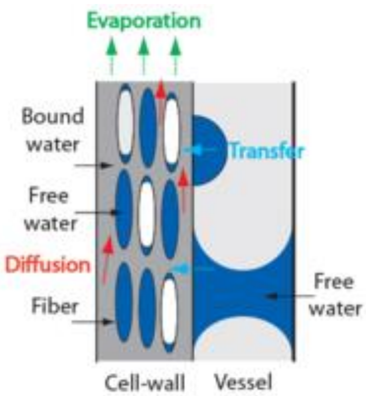


Figure 4: Water movement in wood

During wood drying, even well above the fiber saturation point, bound-water diffusion in cell walls (instead of capillary effects) ensures the extraction of liquid water from pores and its transport towards the surface of evaporation, and thus controls the drying rate.

The distribution of bound-water content (uniform or heterogeneous) along the main sample axis and the drying-rate evolution depend on the competition between the external conditions and a characteristic rate of transport due to bound-water diffusion.

For sufficiently slow drying this distribution remains homogenous until free water is fully extracted.

An original physical phenomenon is thus at work, which plays a major role in regulating water extraction, in that it maintains a constant drying rate and a homogeneous distribution of the (mean) water content throughout the material. In softwoods, since the tracheid are closed at the ends, all flow between adjacent tracheid must go through the pits between the cell walls in a transverse direction. In hardwoods the vessels are basically open at the ends and water flows freely between these ends (very little flow occurs through pits in hardwoods).

Changes in the amount of bound water in wood (below the FSP) affect the physical and mechanical properties of wood. Moisture from the air (water vapor) penetrates dry wood (below FSP) by diffusion, as bound water.

➢ Moisture–Shrinkage Relationship

The shrinkage of a small piece of wood normally begins at about the fiber saturation point and continues in a fairly linear manner until the wood is completely dry.

However, in the normal drying of lumber or other large pieces, the surface of the wood dries first. When the surface gets below the fiber saturation point, it begins to shrink. Meanwhile, the interior can still be quite wet and not shrink.

The result is that shrinkage of lumber can begin before the average moisture content of the entire piece is below the fiber saturation point, and the moisture content–shrinkage curve can actually look. The exact form of the curve depends on several variables, principally size and shape of the piece, species of wood, and drying conditions used. Considerable variation in shrinkage occurs for any species. Shrinkage data for Douglas-fir boards, 22.2 by 139.7 mm (7/8 by 5-1/2 in.) in cross section.

Exercise:

1. One piece of wood weighing 20 g when fresh, has a 16 g weight after drying. Calculation of the Moisture content when it was fresh

Answer: ((20 – 16) / 16 x 100 = 25%

2. Who water can move through wood?

Table 2: Shrinkage rate of some wood species

Species	Shrinkage[a] (%) from green to ovendry moisture content		
	Radial	Tangential	Volumetric
Hardwoods			
Alder, red	4.4	7.3	12.6
Ash			
Black	5.0	7.8	15.2
Blue	3.9	6.5	11.7
Green	4.6	7.1	12.5
Oregon	4.1	8.1	13.2
Pumpkin	3.7	6.3	12.0
White	4.9	7.8	13.3
Aspen			
Bigtooth	3.3	7.9	11.8
Quaking	3.5	6.7	11.5
Basswood, American	6.6	9.3	15.8
Beech, American	5.5	11.9	17.2
Birch			
Alaska paper	6.5	9.9	16.7
Gray	5.2	—	14.7
Paper	6.3	8.6	16.2
River	4.7	9.2	13.5
Sweet	6.5	9.0	15.6
Yellow	7.3	9.5	16.8
Buckeye, yellow	3.6	8.1	12.5
Butternut	3.4	6.4	10.6
Cherry, black	3.7	7.1	11.5
Chestnut, American	3.4	6.7	11.6
Cottonwood			
Balsam poplar	3.0	7.1	10.5
Black	3.6	8.6	12.4
Eastern	3.9	9.2	13.9
Elm			
American	4.2	9.5	14.6
Cedar	4.7	10.2	15.4
Oak, white—con.			
Chestnut			
Live	6.6	9.5	14.7
Overcup	5.3	12.7	16.0
Post	5.4	9.8	16.2
Swamp, chestnut	5.2	10.8	16.4
White	5.6	10.5	16.3
Persimmon, common	7.9	11.2	19.1
Sassafras	4.0	6.2	10.3
Sweetgum	5.3	10.2	15.8
Sycamore, American	5.0	8.4	14.1
Tanoak	4.9	11.7	17.3
Tupelo			
Black	5.1	8.7	14.4
Water	4.2	7.6	12.5
Walnut, black	5.5	7.8	12.8
Willow, black	3.3	8.7	13.9
Yellow-poplar	4.6	8.2	12.7
Softwoods			
Cedar			
Yellow	2.8	6.0	9.2
Atlantic white	2.9	5.4	8.8
Eastern redcedar	3.1	4.7	7.8
Incense	3.3	5.2	7.7
Northern white	2.2	4.9	7.2
Port-Orford	4.6	6.9	10.1
Western redcedar	2.4	5.0	6.8
Douglas-fir,			
Coast[b]	4.8	7.6	12.4
Interior north[b]	3.8	6.9	10.7
Interior west[b]	4.8	7.5	11.8
Fir			

Exercise:

1. One piece of wood weighing 20 grs when fresh, has a 16 g weight after drying. Calculation of the Moisture content when it was fresh

Answer: ((20 – 16) / 16 x 100 = 25%

2. Who water can move through wood?

Table 3: Different chemical properties of different wood species

Constituent	Scots Pine *(Pinus sylvestris)*	Spruce *(Picea glauca)*	Eucalyptus *(Eucalyptus camaldulensis)*	Silver Birch *(Betula verrucosa)*
Cellulose (%)	40	39.5	45.0	41.0
Hemicellulose				
-Glucomannan (%)	16.0	17.2	3.1	2.3
-Glucuronoxylan (%)	8.9	10.4	14.1	27.5
-Other polysaccharides (%)	3.6	3.0	2.0	2.6
Lignin (%)	27.7	27.5	31.3	22.0
Total extractives (%)	3.5	2.1	2.8	3.0

Wood: elementary composition of wood (amount of C, H, O):

- C-49.5% (average values)
- H- 6.3%
- O- 44.2% Elementary composition is almost the same for all of wood species

Table 4: Chemical elements in wood of trunk

WOOD	Elements (%)			
	C	H	O	N
spruce	50,3–51,4	6,1–6,3	41,6–43,1	0,1–0,9
fir	50,4–51,3	5,9–6,0	43,4–44,0	0,1–0,8
pine	49,5–49,6	6,4	44,0–44,4	0,9
oak	49,4–50,6	6,1–6,2	41,8–44,5	1,2
beech	48,5–50,9	6,1–6,3	42,1–45,2	0,12–0,9

The chemical compositions were consistent with the composition of tropical woods reported in previous literature, with an ash content of 4.8% to 6.8% and total extractible content in the range of 15.4% to 28.5%.

The lignin content was in the range of 17.6% to 24.0%, while the range of holocellulose was 53.9% to 63.0%. The chemical compositions were consistent with the composition of tropical woods reported in previous literature, with an ash content of 4.8% to 6.8% and total extractible content in the range of 15.4% to 28.5%.

The lignin content was in the range of 17.6% to 24.0%, while the range of holocellulose was 53.9% to 63.0%.

Table 5: Chemical Compositions of the Firewood Species

Species	Extractable (%)			Extractable Total (%)	Lignin Klason* (%)	Holocellulose** (%)
	Benzene-ethanol	Ethanol	Water			
S. gaumeri	8.65[b] (0.16)	5.13[a] (0.17)	14.12[a] (0.95)	27.90[a] (1.28)	17.64	54.46
H. albicans	5.54[c,d] (0.62)	4.00[a,b,c] (0.87)	7.10[c] (0.16)	16.65[d] (0.09)	21.57	61.88
L. latisiliquum	4.74[d] (0.01)	4.90[a,b] (0.19)	14.33[a] (0.17)	23.96[b] (0.16)	19.89	56.15
C. glabellus	6.63[c] (0.28)	2.35[c,d] (0.60)	9.21[b] (0.05)	18.19[c,d] (0.28)	20.59	61.22
L. yucatanensis	10.29[a] (0.04)	0.75[d] (0.11)	8.72[b,c] (0.71)	19.66[c] (0.91)	19.37	62.84
N. emarginata	8.11[b] (0.01)	3.05[b,c] (0.35)	7.15[c] (0.33)	18.30[c,d] (0.20)	23.95	57.75

Table 6: Chemical composition of softwood and hardwood

	Softwoods	Hardwoods
Cellulose	40-50%	40-50%
Lignin	25-35%	20-25%
Hemicelluloses	20-30%	25-40%
Extractives	0-25%	0-25%

Table 7: Elemental Analysis and Fuel Characterization of Firewood Samples.

Species	Elements, Weight Percentage (%)					Calorific Values (kJ/kg)	Density (g/cm³)	Moisture (%)	Ash (%)
	C	H	O	N	S				
S. gaumeri	44.65[b] (0.01)	5.92[a] (0.06)	49.35[b] (0.06)	0.08	0.00	17514[b] (55)	1.126[a] (0.62)	8.32[a] (0.52)	5.83[b,c] (0.05)
H. albicans	42.66[c] (0.14)	5.64[a,b] (0.11)	51.63[a] (0.25)	0.01	0.06	16293[c] (193)	1.030[a,b] (0.059)	9.84[a] (0.12)	6.82[a,b] (0.57)
L. latisiliquum	43.81[b,c] (0.35)	5.61[a,b] (0.07)	50.53[a,b] (0.28)	0.00	0.05	16763[b,c] (67)	0.591[b] (0.023)	8.40[a] (0.18)	4.77[c] (0.42)
C. glabellus	44.81[b] (0.09)	5.71[a,b] (0.05)	49.44[b] (0.14)	0.00	0.04	17326[b] (101)	0.876[b] (.086)	8.67[a] (0.14)	5.30[c] (0.26)
L. yucatanensis	48.82[a] (0.64)	5.18[b] (0.14)	45.98[c] (0.81)	0.00	0.02	18452[a] (462)	1.006[a,b] (0.030)	8.34[a] (0.93)	5.87[b,c] (0.58)
N. emarginata	43.61[b,c] (0.28)	5.22[b] (0.25)	51.11[a] (0.04)	0.00	0.06	16200[c] (177)	0.846[b] (0.068)	8.72[a] (0.13)	7.22[a] (0.22)

1.2. Wood physical properties affecting wood drying process

1.2.1. Key definitions

- **Wood Physics** is a branch of wood science which deals with the non-mechanical properties of wood.
- Physical properties are the quantitative characteristics of wood and its behavior to external influences other than applied forces.
- **Anisotropic:** Exhibiting different properties along different axes; in general, fibrous material s such as wood are anisotropic.
- **Early wood**: Portion of the annual growth ring that is formed during the early part of the growing season; it is usually less dense and mechanically weaker than latewood.
- Hardwoods General botanical group of trees that has broad leaves in contrast to the conifers or soft woods; term has no reference to the actual hardness of the wood.
- **Latewood:** Portion of the annual growth ring that is formed after the early wood formation has ceased; it is usually denser and mechanically stronger than early wood.
- **Softwoods**: General botanical group of trees that in most cases has needlelike or scale like leaves (the conifers); term has no reference to the actual hardness of the wood.
- **Ring-porous woods:** Group of hardwoods in which the pores are comparatively large at the beginning of each annual ring and decrease in size more or less abruptly toward the outer portion of the ring, thus forming a distinct inner zone of pores, the earlywood, and an outer zone with smaller pores, the latewood.
- **Annual growth ring:** Layer of wood growth put on a tree during a single growing season. In the temperate zone, the annual growth rings of many species (e. g., oaks and pines) are readily distinguished because of differences in the cells formed during the early and late parts of the season; in some temperate zone species (e. g., black gum and sweet gum) and many tropical species, annual growth rings are not easily recognized.
- **Diffuse-porous wood**: Certain hardwoods in which the pores tend to be uniformly sized and distributed throughout each annual ring or to decrease in size slightly and gradually toward the outer border of the ring.
- **Density:** Weight per unit volume. Density of wood is influenced by rate of growth, percentage of late wood and in individual pieces, the proportion of the heartwood.
- **Grain:** The direction, size, arrangement, appearance, or quality of the fibers in sawn wood. Straight grain is used to describe lumber where the fibers and other longitudinal elements run parallel to the axis of the piece.
- **Heartwood:** The inner layers of wood in growing trees that have ceased to contain living cells. Heartwood is generally darker than sapwood, but the two are not always clearly differentiated.
- **Sapwood:** The outer zone of wood in a tree, next to the bark. Sapwood is generally lighter than heartwood.

- **Stain:** Materials used to impart color to wood
- **Texture:** Determined by relative size and distribution of the wood elements. Described as coarse (large elements), fine (small elements) or even (uniform size of elements).
- **Weight:** The weight of dry wood depends upon the cellular space, the proportion of wood substance to air space.
- **Figure:** The pattern produced in a wood surface by annual growth rings, ra**ys,** knots, deviations from regular grain, such as interlocked and wavy, and irregular coloration.
- **Split:** Separation of the fibers in a piece of wood from face to face (other term: end-split).

Exercises
• Group discussion: Differentiate heart wood with hardwood, earlywood with laterwood, and softwood with sapwood,

1.2.2. Wood structure

➢ Wood structure level

- Gross structure of wood:
  - Visible to the naked eye
  - Heartwood/sapwood, growth rings, grain, knots
- Microstructure of wood
  - Visible under a light microscope
  - Different cell types, morphology of cells

Macro- & micro-structure

THE FIBRE (CELL)

- The cell wall
  - Visible by electron microscopy (some features by optical microscopy)
- Chemical composition
  - Spectroscopic & chemical techniques

Ultra-structure & chemistry

- Providing background to:
  - Appearance
  - Properties
  - Behaviour

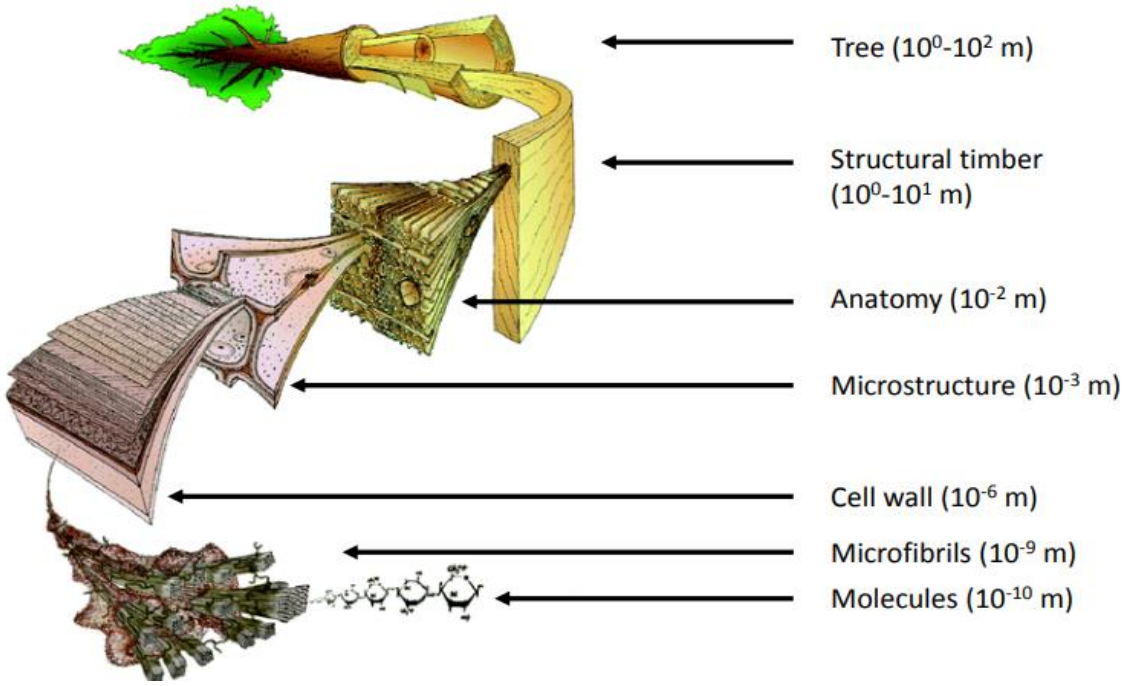


Figure 5: Hierarchy of wood

➢ Microstructure

Microscopic structure of wood: Part of the wood structure which can only be seen with a strong lens or a microscope.

For identification purposes, magnifications of 50 to 200x are normally adequate and as much as 500x is rarely necessary. When studying details of cell wall composition, on the other hand, electron microscopes and magnifications up to 100,000x may be employed.

The primary structural building block of wood is the tracheid or fiber cell. Cells vary from 16 to 42 µm in diameter and from 870 to 4000 µm long.

Thus a cubic centimeter of wood could contain more than 1.5 million wood cells.

When packed together they form a strong composite. Each individual wood cell is even more structurally advanced because it is actually a multilayered, closed-end tube rather than just a homogeneous-walled, no reinforced straw. Each individual cell has four distinct cell wall layers (Primary, S1, S2, and S3).

Each layer is composed of a combination of three chemical polymers: cellulose, hemicellulose, and lignin. The cellulose and hemicellulose are linear polysaccharides (i.e., hydrophilic multiple-sugars), and the lignin is an amorphous phenolic (i. e., a three dimensional hydrophobic adhesive). Cellulose forms long unbranched chains and hemicellulose forms short branched chains. Lignin encrusts and stiffens these polymers.

Wood composed of **cellular tissue** that has different functions

Cells aligned either parallel (mainly “grain direction” ~90%) or perpendicular (“rays”) to the axis of the tree

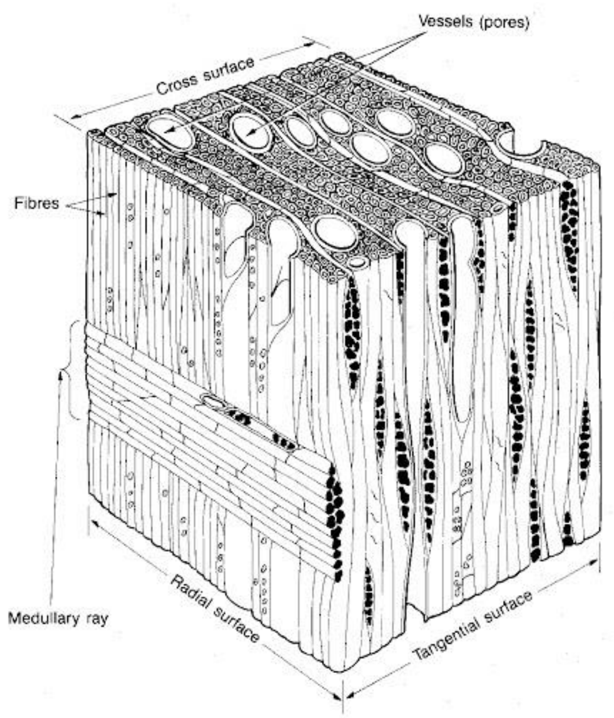


Figure 6: Hardwood cell structure

Exercises
• Identify microstructure of pinus and Eucalyptus wood

Structure of the wood cell wall

Features:

- Tube like structure
- Wall thickness depends on function
- Void space in the center is called the ***lumen***
- Structures known as **pits** connect cells
- Formed by cell division

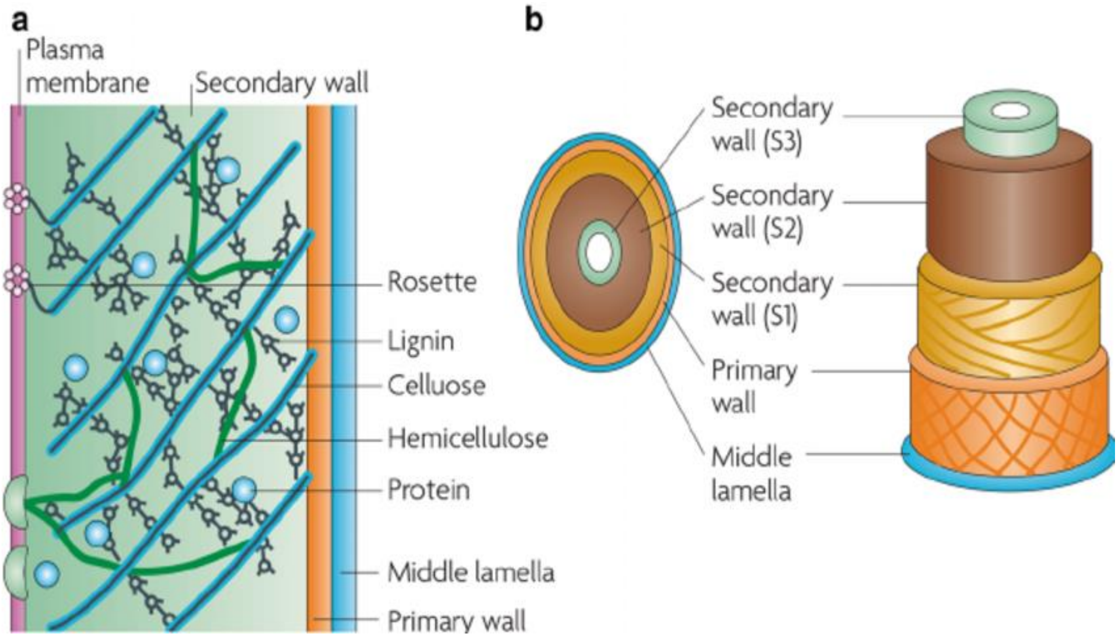


Figure 7: Structure of the wood cell wall

Table 8: Wood cell types

Soft wood	Hardwood
• Tracheid (support and conduction) • Parenchyma (storage- mainly in the rays) •	• Tracheid • Parenchyma • Fibres (Thick walled cells) whose main function in mechanical support • Vessels (or pores), specialized conductive tissues

- **Fibres**: elongated cells, dead and empty when functional. The cell wall surrounds the lumen. Their function is to t**ransport** *fluids*, and/or for *strengthening.*
- **Parenchyma**: these are 'brick-like' cells. Unlike tracheid, wood parenchyma normally lives for many years. ***Wood with living parenchyma is known as sapwood***. When the cells die the wood becomes known as ***heartwood*** and this occurs towards the center of the tree.
- When the cells die the cell contents are converted to waste products that are known as **extractives**. Parenchyma can be in the **rays** (ray parenchyma) where the cell's long-axis is horizontal or in the wood (wood parenchyma) where the long axis is vertical
- **Tracheid**: are fibres whose function both **conduction and strengthening**
    - ✓ Early wood conduction
    - ✓ Latewood support
- **Vessels**: are vertical tubes that are formed from a stack of cells that have lost or partially lost their end walls. Their function is for the rapid transport of fluids. Vessel elements are stacked one on top of the other for form the long tube-like vessels.

➢ Cell types in softwoods

More than 90 % of the volume of a softwood stem is made up of one type of cells, the **tracheid**. These are hollow, needle-shaped cells found in soft wood. These are arranged longitudinally in the stem and may attain lengths of as much as 11 mm in the case of *Araucaria cunninghamii*, but are normally between 2 and 4 mm long as in the Pinus, Picea and Abies species. The tracheids are basically hexagonal in cross section and have diameters which vary between 0.015 and 0.1 mm. They are closely packed together and appear like **honey- comb.**

Also the wall thickness of the tracheid varies: in **early wood** the diameter is at its maximum and the wall thickness may be less than **10 % of the diameter**, in **latewood** the diameter is smaller and the wall thickness may be 50 % or more of the diameter.

The length of the tracheid and particularly the ratio of length to width and the ratio of wall thickness to lumen diameter greatly affect the **strength properties of the wood** and the **value of the wood** as raw material for pulp products. Tracheids are specifically for conduction of sap and mechanical strength.

Tracheids with the larger cavity, is better for **conduction fluid,** the thicker the walls the smaller cavity and better for **strength,** thin walled tracheids are found in the **early wood** while thick walled tracheids are found in **latewood**.

Pits are relatively thinner portions of the cell wall that adjacent cells can communicate or exchange fluid through. The size and arrangement of these pits are of particular value in identification of softwood species and in protecting against cavitation by air-seeding

The **ray cells:** these are organized bands of tissues oriented perpendicular to the longitudinal elements are short, brick-like and thin – walled and may be of two types, ray parenchyma (for storage) and ray tracheids (for transport substance).

Rays extend radially from the pith at the centre of stem to the cambium and continues into phloem. Ray cells are on an average 0.1 – 0.2 mm long. Ray parenchyma cells have simple pits and the ray tracheids bordered pits.

Ray cells

Rays cells form “bands” or “flecks” on the tangential surface. That are clearly visible in some species (e.g. beech) and can also be seen in other species like oak). They can be “**uniseriate**”, i.e. they are only one cell wide, **or multiseriate** (or bi-, tri-seriate). This is a useful aid in identification.

Exercise:
1. Differentiate the wood cells in softwood species 2. What are the roles of tracheid and ray in soft wood species

In softwoods the rays are mostly **uniseriate**. The softwood rays may further be of three different types, i.e. **homogeneous** and consisting of only ray parenchyma cells, **heterogeneou**s and consisting of ray parenchyma and ray tracheids, or fusiform and including a resin canal within the body of the ray.

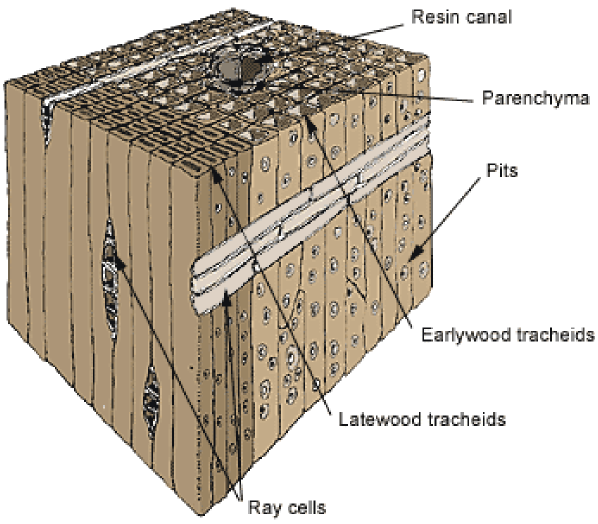


Figure 8: Softwood cell structure

Cell types in hardwoods

1. **Vessel:** The long, narrow tube arising from a number of vessel cells joining longitudinally. Vessel are the conducting cells found only in hardwood.

The length of a vessel element varies from less than 0.3 mm to over 1.0 mm and for most species is about 0.5 mm. The diameter varies more, from an average of less than 0.05 mm in some species to over 0.4 mm in others. Wall thickness may be 5 to 10 % of vessel diameter. The vessel elements may vary greatly within a growth ring with very **large diameters in the early wood** and much **smaller diameters in the latewood.**

This is a typical picture of the ring porous hardwoods; in the diffuse porous species the vessel diameters are more or less uniform throughout the growth ring. Some tree species have vessels in which the walls show spiral thickenings which prevent the vessels from collapsing inwards when their internal pressure is less than the pressure outside.

The walls of the vessels are well endowed with openings, or pits which permits the movement of water between adjacent vessels. The pits on the walls of adjoining vessels are bordered pits. The vessels may make up as much as 50 % of the volume of a hardwood stem.

2. The tracheid

The vascular tracheids are similar in shape, size and position to the smaller latewood vessels and are arranged vertically as the vessels with which they are associated. The vascular tracheid has imperforate ends and walls with a large number of bordered pits. Their function is the same as that of the vessels and is difficult to distinguish from small vessels, especially in the cross section**.** Vascicentric tracheids are shorter than the vascular tracheids and are mainly found adjacent to large early wood vessels. The Vascicentric tracheid have tapered ends and walls with bordered pits.

3. Fibres: longitudinally elongated cells with the main function of giving support to the stem. The fibers are of similar shapes as the softwood tracheid that is they have pointed, closed ends are relatively thick-walled with wall thickness of about 0.01 mm and are in the order of 1.0 mm long. Two subtypes of fibres: fibre tracheids which have bordered pits and the libriform fibres with simple pits. The fibres constitute roughly 25 % of the volume of hardwood stems.

4. The axial parenchyma cells: are in shape and size comparable to the fibres, but are thin walled as the ray parenchyma. The axial parenchyma contains protoplasm and frequently store starch.

5. Ray parenchyma cells Upright and Procumbent

The upright cells are oriented longitudinally in the stem, the procumbent radially.

The pits are simple or bordered, depending on the neighboring cells, simple if the adjacent cells are ray parenchyma cells, bordered when the neighbors are vessels or fibres. The parenchyma in hardwoods constitutes 15 to 20 % of the wood volume.

LEARNING UNIT 2: SEASON TIMBER

2.1 Select timber drying methods

2.1.1. Key definitions

Timber seasoning defined as the process of drying out the water from "wet" or "green" timber is termed "seasoning", or more simply "drying". Water is just as essential to the life of a tree as it is for all living matter.

Together with the various minerals, it enters through the roots of the tree and is carried in the sapwood - the outer woody part - to the leaves. Drying will make the timber/wood stable in dimensions; meaning timber/wood that is not dry enough will not maintain its original size even if it is machined accurately. Average moisture content of a load: estimated value calculated by averaging moisture content values obtained from several samples in the load.

Collapse: Excessive and often uneven shrinkage during drying caused by the collapse or buckling of the cell walls.

Drying defect: A feature developed during drying which may decrease the value of a piece of timber.

Drying schedule: A sequence of kiln conditions which result in a gradual decrease in moisture content of the wood. Twelve standard schedules varying from mild to severe are recognized. Timber species are assigned to the schedule which will achieve the fastest drying with an acceptably low level of degrade.

Green timber/ wood: Wood which still contains its original free moisture.

Hygrometer: An instrument for measuring the humidity of air.

Kiln: A closed chamber in which the air temperature, humidity and movement can be adjusted to control the drying of timber.

Split: A drying defect which occurs when tensile stresses cause the wood fibers to separate and form cracks. Splits are cracks which extend across a piece.

2.1.2. Timber drying principles

The basic principle of wood drying is on the premise of guarantee the quality of drying to improve the drying speed, saving energy consumption, reduce the cost of drying. Drying quality refers to: must make be dried wood moisture content and drying uniformity can satisfy the requirement of processing technology; Must also maintain the integrity of the wood craft standard not occurred, do not allow defects, not weaken due to the nature of the wood and its products.

The drying speed is to point to, in unit time the degree of lumber moisture content is lower.

The faster the drying (or the shorter the drying cycle), need drying equipment and investment is less, the higher the productivity, the less cost of drying.

When choosing drying equipment production, according to be dried wood species, specification, quantity, purpose and production unit of realistic condition, etc**.**

For modern wood drying room, for drying medium on craft can guarantee temperature, humidity and air velocity, stow by the external conditions of dry timber basic same, in order to achieve the purpose of uniform drying, safe and reliable in operation, flexible control, small labor intensity of workers. Less investment in equipment, covers an area of small, quick effect, saving energy, it should also reduce the amount of pollution on the surrounding environment as much as possible.

2.1.3. Environmental condition for timber drying

➢ **For Air drying**

Timber/ pole yard should be made:

- The yard should be spacious/ large and have free flow of air;
- Narrow yards should be preferred for better air circulation;
- Yards located near lakes or rivers as a rule are well ventilated due to frequent and powerful movement of air over water;
- Slightly sloping ground with gravel on the floor to facilitate drainage;
- Growing grass/weeds should be removed so as to encourage air movement around the stacks;
- Low piles/loads should be preferred for rapid and uniform drying;

- The foundation for piles must be **solid and strong**.
- High enough (at least 40 cm) from the ground to secure adequate air circulation.
- The piles should be protected against rain and sunshine.
- Where there is a dominant wind direction, it may pay to have the long axis of the yard and the stacks normal to this direction.
- Start with a good foundation. Various materials such as railroad crossties, treated wood beams or concrete blocks can be used to build the foundation and support the stack.
- The supports should be tall enough so the first layer of boards to be dried is at least 12 inches above the ground.
- They should be spaced no more than 24 inches apart to provide adequate support for the lumber stack.
- The cross-supports should be aligned because any low or high spot or twist from opposite corners of the stack will result in lumber with the same amount of warp.

➢ Kiln dying

- Infrastructures (electricity, accessibility,)
- Low humidity, Topography
- Nearby forest, Land ownership,
- The site should be having a good drainage
- The site should be levelled and should be safe from risks such as, flooding and landslides
- Site should have suitable road access;
- Site should have access to essential services such as water supply, work, schools, and health care.

2.1.4. Timber drying factors

Drying Temperature affects the speed of the drying very much. Wood will dry very quick but it is more likely to have drying defects. The amount of water that air can hold increases with increasing temperature. It therefore follows that by increasing temperature the rate of drying may be increased.

On the other hand, wood in general and wet wood in particular is softened at high temperatures. Substantial strength loss can result in an increase in structural damage, occurring in the wood during drying.

Relative humidity (RH): If it is low, there is only little water in the air, so the wood can evaporate a lot of water. If we are drying too quickly, we will get grain defects.

Speed of air circulation: Another factor to increase the speed of the drying process. Good air circulation will lead to a high rate of drying and for instance if the air surrounding drying wood becomes stagnant it will gradually tend towards equilibrium with the wood, and hence drying will slow down.

Vapor pressure and relative humidity;

The availability of heat; energy

Air circulation: Good air circulation will lead to a high rate of drying. For instance, if the air surrounding drying wood becomes stagnant it will gradually tend towards equilibrium with the wood, and hence drying will slow down.

Drying temperature: The amount of water that air can hold increases with increasing temperature. It therefore follows that by increasing temperature the rate of drying may be increased. On the other hand, wood in general and wet wood in particular is softened at high temperatures.

Substantial strength loss can result in an increase in structural damage, occurring in the wood during drying.

2.1.5. Objectives Timber drying

- To dry the material to a low uniform moisture content with a minimum amount of degrade in a minimum amount of time with a minimum cost for operating expenses and equipment,
- Remove of sap which is harmful for life of timber.
- Seasoning reduces gross weight and thereby subsequent shipping and handling costs,
- Imparts dimensional stability,
- Increases fastener holding power and thereby joint strength,
- Increases electrical resistance,
- Improves the thermal properties of wood.
- Drying will increase the strength of the wood and it is easier to treat with preservatives
- Seasoned wood will not decay as easy as unseasoned because insects of fungi cannot attack it that easily.

- Machining, gluing, sanding and other finishing processes can be done easier and more effective with seasoned wood.
- Transport of wood the reduction of weight is very important because it will be cheaper

2.1.6 End uses of timber with moisture content range

Table 9: End uses of timber with moisture content range

Moisture content	Situation
20%–22%	Limit of good air-seasoned wood
20%	Limit of dry rot occurring
16%	Outdoor furniture
12%–14%	Occasional heated areas, bedroom furniture
11%–13%	Living room furniture, well-heated areas
9%–11%	High degree of central heating, office furniture

Table 10: Maximum permissible moisture content

		MAXIMUM PERMISSIBLE (%)		
No.	Products	MC range		
1	Beams& rafters	12	to	20
2	Doors& windows	10	to	16
3	Furniture	10	to	15

2.1.7. Timber drying methods

Seasoning aims at drying a set quantity of timber uniformly to the equilibrium moisture content required with a minimum of degrade in the shortest possible time. There are many ways of seasoning or drying timber, but only two methods have been found satisfactory, principally for economic reasons. They are air drying and kiln drying seasoning aims at drying a set quantity of timber uniformly to the equilibrium moisture content required with a minimum of degrade in the shortest possible time.

There are many ways of seasoning or drying timber, but only two methods have been found satisfactory, principally for economic reasons. They air drying and kiln drying

➢ Air drying methods

This is the traditional method of drying, practiced for thousands of years. Most of the worlds' timber is air dried. In this process timbers are arranged in layers in a shed.

The arrangement is done by maintaining some gap with the ground. So, platform is built on ground at 300 mm height from ground. The logs are arranged in such a way that air is circulated freely between timber where the vertical and horizontal air circulation is enhanced.

By the movement of air, the moisture content in timber slowly reduces and seasoning occurs. Even though it is a slow process it will produce well-seasoned timber about 15-20% of moisture content. The method aims at making the best use of air circulation, the sun, relative humidity can be influence, while protecting timber from rain.

Through circulation wind prevents air from becoming saturated with moisture absorbed from drying lumber. High temperature lowers the relative humidity of the air.

In order to achieve good seasoning, yard layout need to be considered. Air drying is the simplest method of drying wood important points to be noted and taken care of:

- Proper piling or stacking of the timber.
- Protection of stack from hot winds, blazing sun and rain

Set-up of air timber drying method

The wood should be stacked in a well-ventilated area, which has a roof to prevent direct heat and heavy rain will damage the timber.

The way of stacking the wood is very important for the drying process. There must be free circulation of air over the wood surfaces. There should be a clear space underneath the stack and the bottom layer of the wood should be at least 40-50 cm from the ground level.

The wood should be laid flat with stickers of about 25 mm thickness. The whole stack should be placed perpendicular to the main direction of the wind and sun.

The stickers between the layers of the wood should be about 2.5 cm x2.5 cm in the crosscut or perpendicular position of stacked timbers.

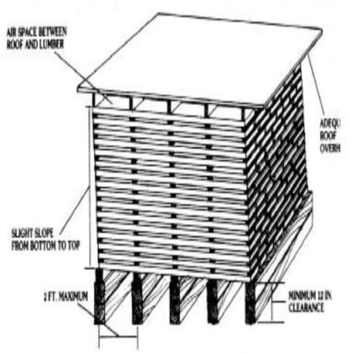
Depending on the species of wood it can be advisable to put some weight on top of the stack to keep the wood from warping and twisting.

The ground below the stack should be concrete or graveled to prevent the attack of insects and fungi and stagnant of water. There should be no grass or bushes growing in the area.

The end grain of the pieces of timber should be coated with a layer of waterproof substance, because the ends are drying faster and end splitting may occur. Another way to coat the end grain is to nail strips or end plate on end of timber.

Set-up of air timber drying method include:

- The timber yard should be spacious and have free flow of air;
- Narrow timber yards should be preferred for better air circulation;
- Timber yards located near lakes or rivers as a rule are well ventilated due to frequent and powerful movement of air over water.



- Advantages of air drying method
    - ✓ Low capital cost, maintenance and requirements;
    - ✓ No special skills or training are necessary;
    - ✓ No steam, smoke, gases or other environmental irritants.
- Disadvantages of air drying
    - ✓ The drying time is long because the process depends on obtaining natural drying conditions.
    - ✓ Pines may stain badly if allowed to air dry;
    - ✓ The lumber is accountable to considerable damage (seasoning defects).
    - ✓ There is no control over the moisture content to which lumber is dried;

2.1.8 Kiln drying method

Kiln seasoning is drying in a closed chamber, providing maximum control of air circulation, humidity and temperature. Air is circulated through stacks by fans. The fans are kept running at constant speed to maintain uniform flow. The principles of stacking are similar to those for air drying. Under these conditions, drying is regulated and minimum shrinkage degrades and lower moisture content are achieved than is possible with air drying.

Kiln drying of lumber is perhaps the most effective and economical method available

Drying rates in a kiln can be carefully controlled and defect losses reduced to a minimum. Length of drying time is also greatly reduced and is predictable so that dry lumber inventories can often be reduced.

Where staining is a problem, kiln drying is one the only reasonable method that can be used unless chemical dips are employed. Kilns are usually divided into two **classes-progressive and compartment**.

In the progressive kiln, timber enters one end and moves progressively through the kiln much as a car moves through a tunnel Temperature and humidity differentials are maintained throughout the length of the kiln so that the lumber charge is progressively dried as it moves from one end to the other.

Progressive kilns may be further subdivided into natural draft kilns in which heated air is allowed to rise through the material by natural convection, and forced draft kilns in which fans are employed to force the air through the wood.

- Its rapidity; Adaptability, Precision;
- It ensures a dependable supply of seasoned timber at any season of the year;
- It is the only way to condition timber for interior use;
- The process fumigates the timber;
- Resins or gums present in certain timber species are set or hardened, reducing the risk of subsequent “bleeding/drainage” from finished surface

2.2 Describe Safety and health measures at timber drying sites

2.2.1. Hazards at timber drying site

Hazard – means something in the work environment that has the potential to cause harm to the health and safety of people. Or it is a situation that has the potential to harm a person. Substances, events,can constitute hazards when their nature would allow them, even to cause damage to health, life, property, or any other interest of value. Hazards can be classified as natural, anthropogenic, technological.

Risk: is the chance (or probability) that a hazard will cause harm to the health and safety of people. Or a risk is the possibility that the harm (i.e. death, an injury or an illness) might occur when exposed to a hazard.

Identify hazards source at timber drying

The following are the Occupational Safety and Health Administration regulations specific to dry Kilns and Facilities.

- Passage ways required in kilns
- Escape panel or special exit door openable from inside and in or by the main loading doors
- Means to hold kiln door open. Means to prevent main doors from falling
- Guard door counter weights, machine belts, pulleys and rotating equipment
- Solid foundations for straight tracks
- Cars and tracks to be in good repair.
- Block wheels of loaded cars on inclined tracks
- Stickers not to protrude hazardously (2" max)
- Pickup and unloading areas to have stops and well-marked areas for spotters.

➢ Hazards in timber yard

- Vehicles and mobile plant
- Uneven surface
- Unstable stacks
- Overhead cables
- Limited vision

- Fire
- Dust

➢ Hazard in stacking of timber yard

- Cuts
- Eye injury

➢ Hazards associated with fire pits and waste disposal systems

- Heat and burns
- Fire
- Explosion
- Smoke

➢ Hazardous chemicals

- Hazardous chemicals have the potential to cause **harm to persons**, **property**, and the **environment**.
    - ✓ Classes of hazardous chemicals
    - ✓ Toxic
    - ✓ Harmful
    - ✓ Corrosive
    - ✓ Irritant
    - ✓ Carcinogenic (causing cancer)
    - ✓ Mutagenic (causing genetic damage)
    - ✓ Teratogenic (causing abnormalities of the fetus).

➢ Specific hazards associated with gas/electric kilns

- Steam, Gas.
- Heat
- Electrocution
- Humidity.
- Entrapment
- Confined space
- Burns

- Fire
- Explosion
- Smoke

➢ **Physical Hazards**

A physical hazard is a type of occupational hazard that involves environmental hazards that can cause harm with or without contact.

- Hazardous temperature
- Stacks of wood
- Heavy wind

2.2.2. Risk Control measures at drying site

This is the most important step in managing risks – **eliminating the identified hazard**

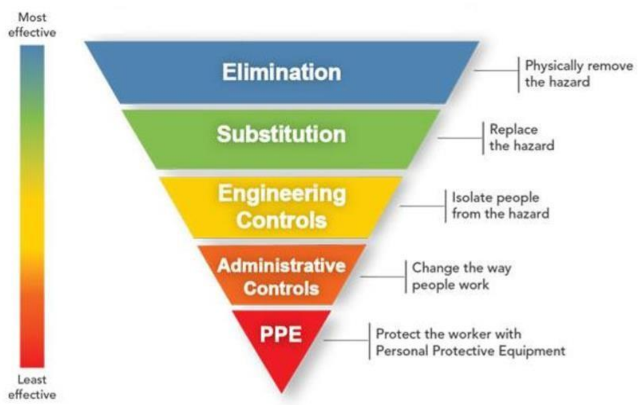
The ways of controlling risks can be **ranked from the highest level** of protection and trustworthy to the lowest. If elimination is not reasonably practicable, the Persons Conducting a Business or Undertaking (PCBU) must minimize the risk so far as is reasonably practicable by **doing one or more of the following**:

Substituting (wholly or partly) the hazard creating the risk with something that creates a lesser risk.

Isolating the hazard from any person exposed to it. **Implementing** engineering controls.

Administrative controls and PPE should only be used:

- When there is no other practical control measure available
- As a temporary measure until a more effective way of controlling the risk can be used
- To supplement higher level control measures.



2.3 Perform open air drying / natural drying

2.3.2. Factors for air drying

- **Drying Temperature** affects the speed of the drying very much. At high temperature wood will dry very quickly but it is more likely to have drying defects.
- The **amount of water that air** can hold increases with increasing temperature. It therefore follows that by increasing temperature the rate of drying may be increased. On the other hand, wood in general and wet wood in particular is softened at high temperatures. Substantial strength loss can result in an increase in structural damage, occurring in the wood during drying.
- **Relative humidity (RH):** If it is low, there is only little water in the air, so the wood can evaporate a lot of water. If we are drying too quickly, we will get grain defects.
- **Speed of air circulation**: Another factor to increase the speed of the drying process.

2.3.3. Methods of timber stacking

➢ Vertical Stacking

Usually in use for light timbers used for packing cases. Sawn planks are made to stand in open air against a wall or a framework of wood or bamboos. The surface of planks dries rapidly thereby avoiding mould attacks and sap stain.

Figure 9: vertical stacking

If you are going to store seasoned wood vertically indoors, be sure to use a storage system that's raised off the ground so air can flow underneath. Concrete floors might look dry, but moisture can rise up from them and get into your wood if you're not careful. Wood will warp and even rot if it's exposed to moisture for too long.

The storage system should have support **at both the top and the bottom** to prevent bowing. If you have a lot of smaller pieces you can put them in a lumber cart. While it's perfectly fine to store seasoned wood vertically, when it comes to long-term storage, horizontal is probably best.

➢ Horizontal Stacking

Most common practice and is suitable for all kinds of sawn material. Stacking with the help of battens or crosses. Different species and different thicknesses should be stacked separately.

Unseasoned wood should always be stored horizontally. However, once wood is dry (seasoned), how you store it doesn't matter as much. But, provided you have space, it's best to store both types of lumber horizontally.

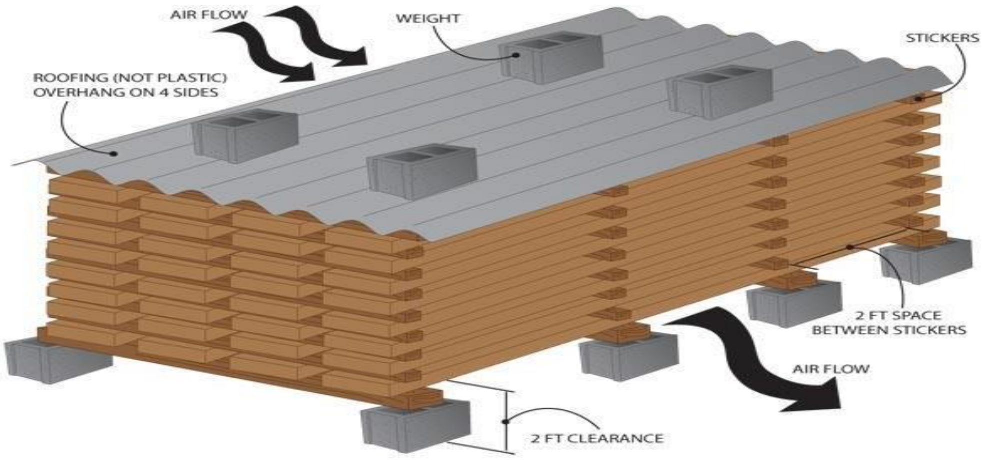


Figure 10: horizontal stacking

Exercise
1. Stack the timber in horizontal and vertical position 2. What is the most common timber practice which is suitable for all kinds of sawn material?

➢ Types of sheds

Shed type 1

For headstrong species i.e. those species which are very likely to **crack, split and warp**.

E.g. *Syzygium cumini*, *Terminalia paniculata*

A closed shed provided with open space for ventilation in walls just below the roof and above the ground. It should have a central passage for loading and unloading or removable side walls.

Shed type 2

For medium headstrong species

E.g. Acacia Arabica, Albizia lebbek Cedrela, Dalbergia, Latifolia, Tectona grandis (Teak). Shed open on one side and closed on three sides

Open side should have sufficient overhang of the roof to protect the stack from direct sun and rain.

2.3.5. Ground Setting out a drying yard

➢ **Layout and Orientation**

An efficient yard layout should provide good drainage of rain and melting snow, free movement of air in and out of the yard, and easy transportation and piling of lumber.

A yard laid out for rapid drying potential should be on high, well-drained ground with no obstructions to prevailing winds. However, the need to keep the yard close to the plant limits site selection, and convenient areas are not always favorable to rapidly air drying lumber and providing a minimum of degrade.

Yard sites bounded by buildings or with standing water or streams nearby should be avoided because this retards lumber drying. Most yards are laid out in a rectangular scheme.

The alleys or roadways cross each other at right angles, and the areas occupied by the piles are rectangular. Specific areas may be designated for certain species, grades, or thicknesses of lumber.

The alleys serve as routes for transporting the lumber, as pathways for the movement of air through the yard, and as protection against the spread of fire.

The alleys in an air-drying yard are classified as main and cross alleys. Main alleys are for access to the lumber stacks and cross alleys are for access to the main alleys.

In large air drying yards, blocks or areas are often separated by still wider roadways or strips of land to protect the lumber from the spread of fire and to meet insurance requirements.

These wide alleys are sometimes called fire alleys. The sides of the lumber piles are parallel to the main alleys, which means air flows through the lumber stacks from one main alley to an adjacent main alley. Spaces between the sides and ends of the piles are also part of the yard layout. These spaces form additional passageways for air movement. Yards can be oriented in either of two ways.

The main alleys run north and south to obtain faster roadway drying after rain or faster snow melt.

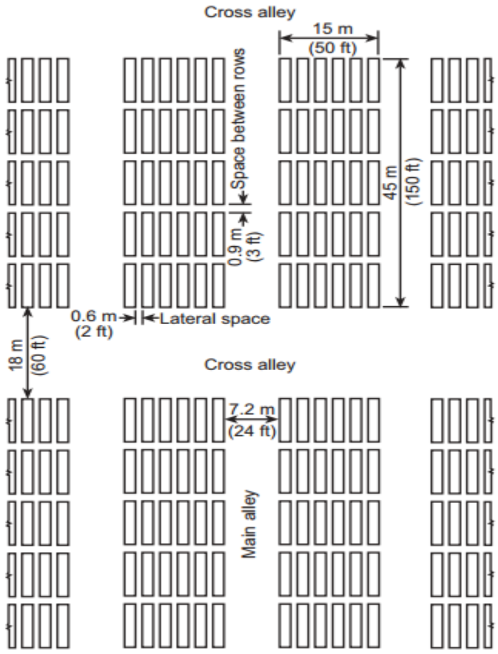


Figure 11: General arrangement of a row-type air-drying yard

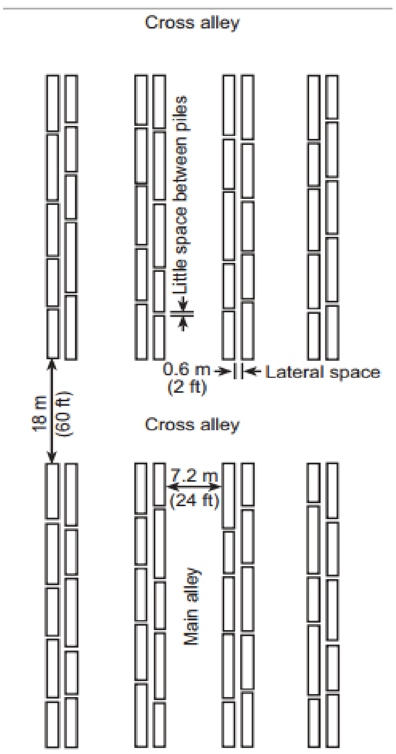


Figure 12: General arrangement of a line-type air-drying yard

➢ Alley Size

Lumber piles are arranged either in rows of approximately six piles (Fig 3) or in lines of two piles (Fig. 4) on the previous figure. The line arrangement is used when the maximum air-drying rate is desired because air only has to flow through two piles rather than six as in the row arrangement.

The main alleys are generally 7 to 9 m (24 to 30 ft) wide. Cross alleys intersect the main alleys at right angles and provide access to the main alleys. Cross alleys also afford protection against the spread of fire and may be 18 m (60 ft) or more in width and spaced every 61 or 91 m (200 or 300 ft).

In addition to providing ample room for the forklift truck to maneuver in and out of the rows, alleys must be wide enough to allow clearance for the longest lumber being handled.

➢ Row spacing

Spaces between the ends of lumber piles aligned in rows should be large enough so that a lift truck can operate easily. The rows should be a minimum of about 1 m (3 ft) apart (Fig. 3). In a line-type yard, the spacing between lines is usually 0.6 m (2 ft).

➢ Lateral Pile Spacing

The spacing between piles varies with differences in climate, yard site, and the character of the lumber.

Pile spacing also varies with the different specific drying defects to be avoided. Where surface checking is the defect most likely to occur, the width of the spaces should be reduced. Where staining is likely to occur, it is desirable to increase the spacing.

In arid regions, during the hot, dry season, piles should be placed closer together than they are during the cool, moist season. In a row-type yard, the space between the piles within the rows should be about 0.6 m (2 ft) but may be as much as 2.4 m (8 ft) in the middle of the row when variable spacing is practiced. The spaces between the ends of piles in a line- type yard are usually 0.3 to 0.6 m (1 to 2 ft).

If the lift truck has a side shifter, the space can be minimized if air movement needs to be reduced.

➢ Pile Width

For air drying, the width of the lumber pile varies from about 1 to 2.4 m (3-1/2 to 8 ft). Piles only 1 m (3-1/2 ft) wide usually consist of several packages of lumber that are to be placed on kiln trucks after air drying.

➢ Pile Height

Pile height usually ranges from about 1.2 to 4.6 m (4 to 15 ft). Sometimes 9-m- (30-ft-) high piles are built using forklift trucks by stacking packages separated by bolsters. High piles of narrow packages are often tied together with long bolsters for stability.

2.3.6. Shade drying

Lumber, particularly the more valuable grades, is sometimes air dried in open sheds (Fig. 31). Drying sheds are usually pole-type structures, although other structural materials such as steel posts and metal trusses and roofing may be used.

The air-drying shed has a permanent roof so that the lumber is not rewetted by rain. In areas or regions where rain wetting unduly extends the drying time in a conventional air-drying yard, shed drying reduces the time required to attain the desired moisture content and maintain quality.

Sheds are generally open so that the sides and ends do not obstruct air movement. Under certain conditions, shade cloth may be used to form walls. It keeps the lumber clean and reduces surface checking of refractory woods.

Shed-dried lumber is usually brighter in appearance than is lumber air dried in a yard because weathering from ultraviolet radiation or discoloration caused by rewetting is prevented.

The shed roof usually extends beyond the piles and protects the lumber from sunshine; therefore, end checking and splitting are also greatly reduced.

Drying sheds are usually loaded by forklift trucks. Pile foundation requirements are the same as for the forklift yard.

The shed floor may or may not be paved. If not, grading may be required, depending upon soil conditions, and perhaps gravel or crushed stone application can be justified. The drying shed can be fairly wide to make up long rows of piles within the bays. Entry to the rows would usually be from both ends of the rows or both sides of the shed.

In contrast, the drying shed may be long and narrow with two lines similar to a line-type forklift yard.

Figure 13: timber drying under shaded area

2.3.7. Timber stacking procedures

To prepare lumber for air drying, it is usually laid up into courses or layers with separating stickers. The objective is to expose the board surfaces throughout the pile to air circulation. The lumber packages are often made of lumber previously sorted by species, size, and grade.

- **Sorting Lumber**

Lumber coming from the sawmill is generally sorted into classifications based on similar drying characteristics before it is sent to the stacker. Sorting facilitates the stacking operations.

- **Species**

Although several softwoods and hardwoods have similar drying characteristics, the species sort is usually made for merchandising purposes. Those woods that dry rapidly without serious degrade can be yarded in areas where drying conditions are favorable.

Species that dry slowly and are likely to surface check can be air dried in yard areas where drying conditions are less severe.

➢ Thickness

The time required to air dry lumber to a predetermined moisture content is greatly influenced by board thickness.

Figure 14: timber stacking processes

➢ Thickness

For example, 50-mm- (2-in.-) thick lumber may require about three times longer to dry than 25 mm- (1-in.-) thick lumber of the same species. Therefore, it is usual practice to segregate the rough sawn lumber by thickness classes for air drying.

One thick board in a course may allow adjacent well-manufactured boards to warp because of lack of restraint. Pre-surfacing miscut lumber to a uniform thickness facilitates stacking and reduces warp, sticker breakage, and sticker deformation.

➢ Width

Some softwood lumber is sawn in the mill to produce certain final dry dressed sizes. These width classes are kept together for drying to reduce sorting and re-handling costs after drying.

Hardwoods are most often sawn to random widths in the sawmill, and width segregation is seldom practical.

➢ Length

Good package buildup by hand or mechanical stackers is best accomplished by sorted length stacking. The main objective is to gain as much restraint to distortion as possible and maintain uniform air flow by good stickering practices. The advantages of sorting for length apply to both softwoods and hardwoods.

➢ Grain

A flatsawn board dries faster than a quarter sawn board, and mills specializing in producing quarter sawn lumber may find it advantageous to sort for this characteristic. Flatsawn lumber is more susceptible to surface checking than is quarter sawn lumber and is often yarded in areas where the drying potential is less severe.
When relatively few quarter sawn boards are produced along with the major production of flatsawn boards, they are seldom segregated.

➢ Grade

The separation of green lumber by grade is generally a matter of keeping like-value lumber together. Higher grades of lumber may be given better protection in the piles or may be shed dried.

➢ Stacking Lumber in Packages

Packages are sometimes stacked by hand, using a crew of one or two people. Packages are made up beside.

2.3.8. Sticker size and quality

The purpose of stickers is to separate each board surface so that air can flow over each surface and evaporate water. Stickers must be selected and placed so that they give adequate support to minimize warping of the lumber and breakage and distortion of stickers.

Important considerations of stickering include:

- Species and grade of wood used for stickers,

- Moisture content of stickers,
- Sticker size and placement in stack,
- and load supports

Stickers are often made from clear, straight-grained lumber

Straight-grained stickers made from the harder woods stay straighter, break less, and generally last longer than irregular-grained stickers from softer woods. Species such as, beech, oak, Douglas-fir make good stickers.

➢ Moisture Content of Stickers

Stickers should be made from kiln-dried lumber. This reduces the chance of sticker stain, which is a discoloration on the surface. The use of heartwood for stickers also reduces staining. In addition, kiln drying reduces the distortion and thickness shrinkage of stickers that could occur in use.

➢ Sticker Width

Wide stickers slow the drying of lumber in the areas of contact; these areas may remain at a higher moisture content than areas of the lumber not in contact with the stickers.

If stickers are too narrow, the lumber or stickers are liable to be crushed. Stickers for hardwoods are usually 1-1/4 to 1-1/2 in wide and should not exceed 1-1/2 in. Stickers for softwoods are generally about 2 in wide and sometimes up to 3 in wide for softer species such as sugar, white, and ponderosa pine.

Stickers are usually 3/4 to 1 in thick. although 1/2- in-thick stickers are sometimes used. The thinner stickers increase the capacity of a kiln and may be adequate for slow-drying species.

They increase air velocity through the lumber stack and tend to make airflow more uniform. Regardless of size of thickness, all stickers within a kiln charge should be surfaced to a uniform thickness.

➢ Sticker Location, Spacing, and Alignment

Good location, spacing, and alignment of stickers reduce warping and minimize end checking and splitting.

Location

Stickers should be placed flush with or very near the ends of boards whenever possible. This will minimize warping at the ends of boards and will also retard end drying to some extent, thus helping to minimize end checking splitting.

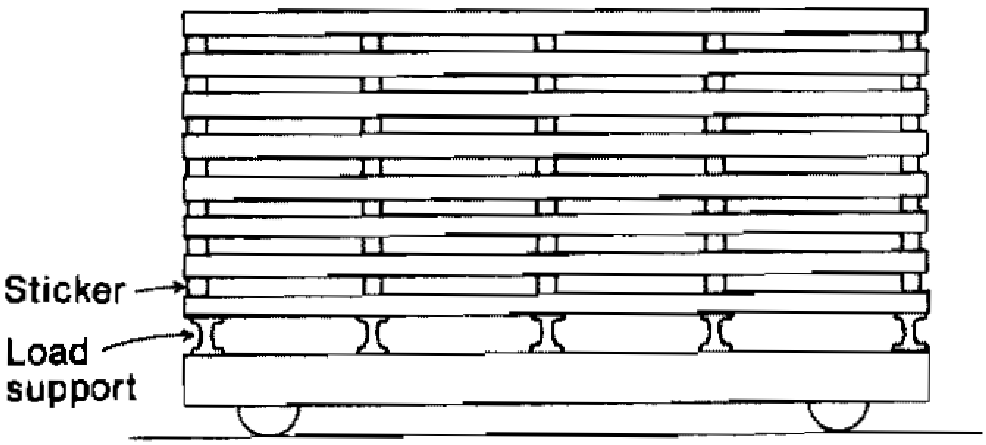


Figure 15: sticker location

Sticker Spacing

Optimum sticker spacing is governed by the lumber's tendency to warp, its thickness, and its resistance to crushing. Hardwoods require closer sticker spacing than softwoods. Some particularly warp-prone species benefit by spacing of less than 2 ft.

Also, to avoid crushing stickers between the bottom courses of heavy loads, sticker spacing may need prevent the end stickers from falling out of the stack.

Alignment

For the best control of warp during drying, the tiers of stickers should be aligned vertically. Misaligned stickers in stacks of green lumber, cause non-uniform distribution of weight and result in sharp bends.

2.3.9 Protection of stacks

When lumber is as dry as can be expected in the air-drying yard, it should be stored where it is no longer exposed to wind, sun, and rain.

The deteriorating effect of weathering continues as long as the lumber is left outdoors. When stickered lumber is taken down and solid stacked, it takes up less space and a shed can provide the needed protection.

When yard space is needed for air drying lumber, less favorable drying areas are often set aside for bulk storage of lumber that has already been air dried. The seasonal changes that influence the air-drying potential of an area also affect the conditions of dry lumber storage.

However, significant moisture changes in air-dried lumber result mainly from rains that rewet the lumber. If good, rain tight pile roofs with adequate projections were used during drying or if the lumber were shed dried, the needed protection from adverse weather was provided.

- **Outdoors**

If the average moisture content of the lumber is greater than 20%, it should be protected in such a way that drying can be continued, as under a roof or in a shed. It should not be bulk piled because of the hazards of stain and decay development.

When the moisture content of the lumber is less than 20%, the piles or packages may be wrapped with plastic tarpaulins or enclosed in prefabricated waterproof wrappings for temporary outdoor storage. Foundations in the storage area should provide good support and ground clearance just as in the original air-drying pile. Support is still essential to prevent pile sagging.

Ground clearance is not only needed to provide room for forklift operations but for ventilation to keep moisture regain in the bottom layers to a minimum. If the water table in the ground is high, a ground cover to provide a barrier to moisture vapor movement out of the soil may be desirable, particularly if the storage period is extended. Indoors Sheds can provide the indoor storage of air-dried lumber. The advantage of shed storage is the protection provided by the permanent roof.

The air-dried lumber is stored in the shed either as stickered unit packages, as bulk-piled lumber in unit packages, or bulk piled in bins or bays. The sheds can be open, closed, or closed and heated; they may or may not be floored or paved. The design, size, and materials of shed construction will vary depending upon plant arrangement, storage volume requirements, and the cost of locally available building materials.

➢ Open-Shed Storage

An open lumber storage shed is one that usually does not have sides or ends to block air movement through the building. Sheds with louvered walls are considered open sheds Wind-blown rain is baffled, a distinct feature of this type of shed.

If the shed is not floored or paved, foundations for stickered or bulked packages of air-dried lumber will be necessary to provide ground clearance for ventilation. When hand-built piles in the yard are taken down, the lumber is often bulk piled in bins or bays in the "rough dry shed."

In a forklift yard operation, the stickered unit packages or packages of bulked lumber are stored in the open shed. The height of the package pile is governed by the height of the shed. Lumber storage volume can be increased by having a forklift available to place carrier packages two, three, or more units high, depending upon the height and construction of the shed.

Figure 16: open sides shed for timber storage

➢ Closed, Unheated Storage

A closed, unheated shed for the storage of air-dried lumber differs from an open shed in that the sides and ends of the buildings are walled, blocking air movement through the structure.

Doorways and other access openings for the transport of lumber in and out of the shed are usually kept closed when activity is not great or the sawmill or factory is not in operation. Partially dry, stickered units of lumber can be stored in a closed shed but, if further drying at a reasonable rate is wanted, the air movement through the stickered package must be stimulated by introducing forced air circulation with fans. As air movement in and out of a closed shed is restricted by the solid walls, some heating of the air in the building results from solar radiation.

If the roof and walls exposed to sunshine are dull black, these structural elements are heated when the sun shines and the air inside the building in contact with these heated elements is warmed. If the closed shed is not floored or paved, foundations must be provided for the unit packages or the lumber in the bins in order to create a space between the ground and the lumber. The walls of the building are often open near the ground level in a closed shed to create air drift or ventilation under the lumber.

These ground-level wall openings can be screened or louvered to discourage entry of birds and small animals into the shed.

Figure 17: a closed, unheated lumber storage shed

2.3.10. Monitoring timbers in stacks

➢ Monitoring and inspection

- Stack condition should be regularly monitored for potential hazards by suitably competent people.
- Stacks should never lean against or be supported by other stacks.
- If a stack is starting to lean, it should be assessed and where necessary restacked.
- A pack that appears out of square, 'lozenge-shaped', will affect the stability of the whole stack. It should be removed from the stack and rectified.

- Do not stack collapsed or partially collapsed packs, reassemble them.
- The stacking area should be kept clear of waste timber or unused bearers to maintain a stable base for the stacks.
- Where possible, assemble outside stacks so a small cross section is facing the normal wind direction. All stacks should be checked after high winds.

➢ Monitoring of timber and pole air drying process

- Air circulation
- Humidity of the site
- Moisture
- Sunshine
- Off-roading

2.4 Set up and operate a dry kiln

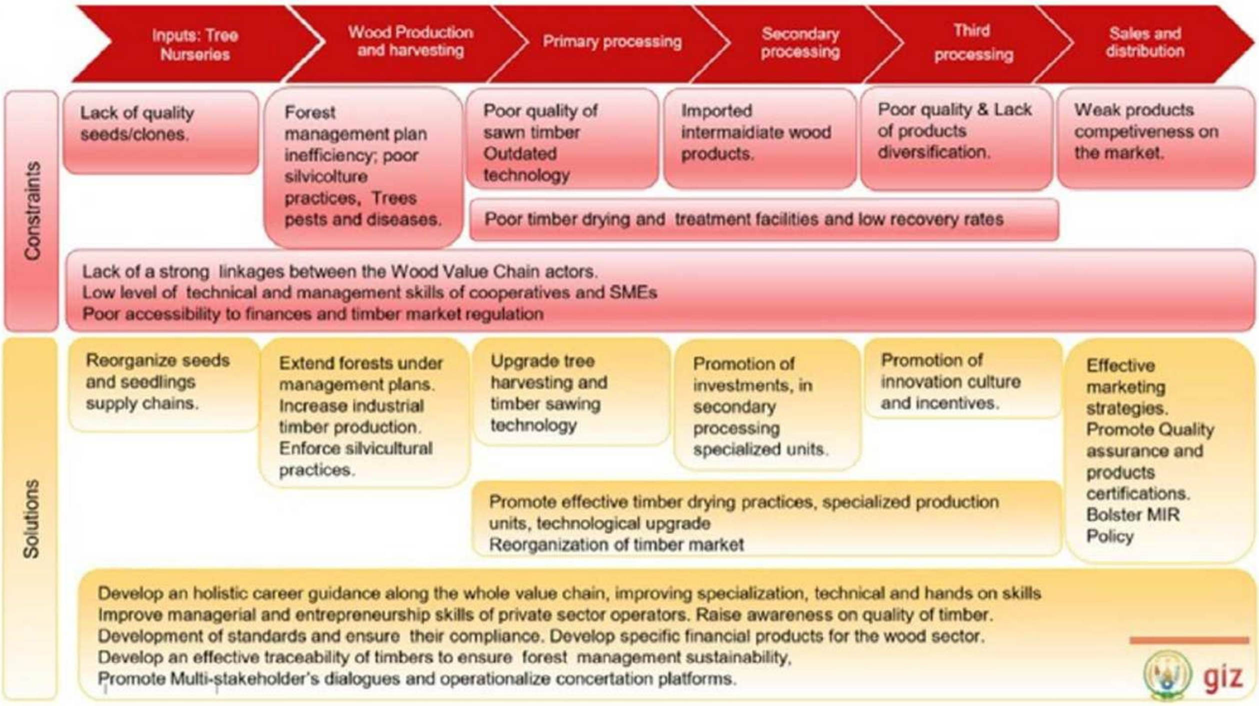
Lumber can be air dried, pre-dried and/or kiln dried. Air-dried lumber will often develop quality losses as a result of unfavorable weather. Kiln drying green-from-the-saw lumber allows control of the drying conditions throughout the drying cycle, thereby assuring excellent quality, but drying time will be longer, energy consumption is higher and costs also.

2.4.1 Criteria for selection of the right kiln design

Lumber can be air dried, pre-dried and/or kiln dried. Air-dried lumber will often develop quality losses as a result of unfavorable weather. Kiln drying green-from-the-saw lumber allows control of the drying conditions throughout the drying cycle, thereby assuring excellent quality, but drying time will be longer, energy consumption is higher and costs also.

What to consider when buying your first dry kiln:

- Cost of drying (investment, ROI return on investment)
- “We dry lumber not to remove moisture but to make money!”
- “The way you make money is to produce the highest possible, quality lumber.”
- “Drying time, energy usage, labor, and other expenses are small compared to the cost of quality loss.” – “THINK QUALITY” – “Quality is a strategic goal!”
- What else? What is the right kiln design for Rwanda?



As the chart of the Wood Value Chain underlines, the quality of the lumber dried in a kiln is predetermined by the manufacturing process prior to kiln drying:

- Protection of logs
- Sawing procedure
- Protection of green lumber
- Prevention of fungal/chemical stain and insect damage
- Prevention of surface checks and end checks
- Sorting and stacking
- Controlling Warp

Company/Name:
Branch:
Contact person:
Street, No.:
Postal code:
Town, Country:
Phone number:
E-Mail:

Dear customer,
Please fill the following form as completely as possible that we can provide you with information and offers which suit exactly to your needs.

Delivery address (if different)

Information on stack dimensions, amount of wood to be dried, chamber size

What is the maximum length of timber to be dried?		m
What is the most common length of timber to be dried?		m
What is the amount (batch size) of timber to be dried at a time?		m³
What is the amount of timber to be dried?		
Per year		m³
Per month		m³
Per week		m³

Type of wood	Amount of wood (m³)	Thickness of Wood (mm)	Initial wood moisture (%)	Final wood moisture (%)
Spruce/Pine	m³	mm	%	%
Larch/Fir	m³	mm	%	%
Beech/Maple/Ash	m³	mm	%	%
Oak	m³	mm	%	%

Available heating energy
What type and amount of heating energy is available?

Electrical: maximum available energy:			kW
Water heating: Flow temp. & available energy:	°C		kW
Steam heating: Steam pressure & available energy:	bar		kW

Type of charging / feeding method
How shall the dryer be charged? Please mark desired method.

☐ From top ☐ long side ☐ Frontally ☐ By fork lift

Dryer with / without housing requested

Offer requested for complete dryer including insulated and vapour-tight housing ☐

Offer requested for equipment without housing ☐

Offer requested for complete dryer as well as for an equipment without housing ☐

Remarks / Notes / Sketches

Kiln set up procedures

1. Create a business plan
2. Decide on a power source
3. Choose a kiln size
4. Kiln construction
5. Kiln control system
6. Choosing a manufacturer
7. Operating a kiln
8. Other equipment necessary

Create a business plan

1. Strategic plan
2. Marketing plan
3. Business and financial planning

Create a strategic plan:

Step 1: Initiating and agreeing on strategic planning

Step 2: Identifying and clarifying values

Step 3: Conducting a stakeholder analysis

Step 4: Developing a mission statement

Step 5: Assessing the external and internal environments

Step 6: Identifying strategic issues

Step 7: Developing strategies to manage strategic issues

Step 8: Implementing and monitoring the strategic plan

… And then go ahead with marketing, business and financial planning

Decide on a power source

1. Choose a kiln size
2. Kiln construction
3. Kiln control system
4. Choosing a manufacturer
5. Operating a kiln
6. Other equipment necessary

Planning of dry kilns (according to Truebswetter 2009 "Holztrocknung",)

- Lumber to be dried? Species? Volume per year? Initial and final MC? Drying schedules?
- Surrounding infrastructure? Roads? Sawmills? Customers? Market? Energy sources?
- Drying method? Air-/pre-drying? Fresh air/exhaust air? Dehumidifier? Vacuum? Solar?
- Operation mode? 24 h/d? 365 d/a? Automation? Loading/unloading? Control system?
- Time of drying one kiln load? Size of kiln? Size of one stack? Net and gross volume?
- Enquire to at least three manufacturers; comparing quotations!
- Investment? Energy consumption? Manpower? Economic feasibility? Business plan?
- Decision and implementation

2.4.2 Kiln drying factors

Three environmental variables control the rate and quality of lumber drying temperature (T) of the air, relative humidity (RH) of the air (can also be expressed as wet-bulb depression), and velocity of the air. Whenever the wood dries too slowly or too rapidly, these variables must be manipulated to achieve the desired drying rate.

Temperature is a measure of how much internal energy an object or gas has. If there are two objects with different temperatures, energy always flows from the warmer object to the colder object.

This also happens inside a kiln when hot air meets a “cold” piece of wood. First, the internal energy of the hot air heats up the wood itself and then the heating energy is needed to evaporate the water what is contained inside the wood.

2.4.3 Relative humidity RH

Humidity tells you the moisture content of the atmosphere, or how much water vapor there is in the air.

Meteorologists measure or talk about humidity in a number of different ways. One of the key measurements they use is relative humidity because this determines how dry the air actually feels. Relative humidity is a function of both how much moisture the air contains and the temperature.

If you raise the temperature while keeping moisture content constant, the relative humidity decreases. The capacity of air to absorb humidity is dependent on the air temperature. The warmer the air, the more water it can absorb.

We can imagine air like a sponge which changes its absorption capacity depending on the temperature.

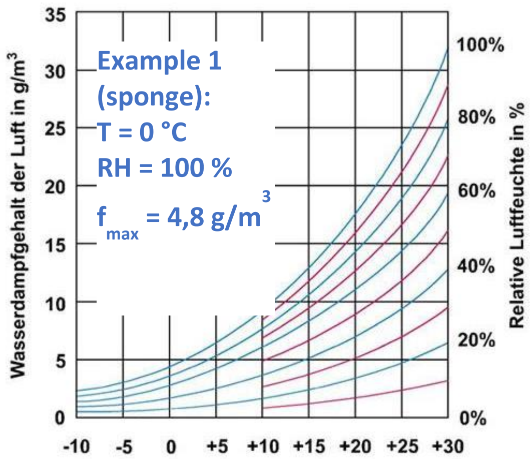
Example 1: At 0 °C, the sponge can absorb 4.8 g of water (corresponds to 100 % RH). At more than 4.8 g, the sponge begins to drip. If the sponge has stored 2.4 g of water, this corresponds to 50 % relative humidity at 0 °C.

At 20 °C, the sponge can store 17.3 g of water (so the sponge has 100 % relative humidity at 17.3 g of water). Now, if the sponge has stored 2.4 g of water at 20 °C, this corresponds to approx. 14 % relative humidity.

- The **absolute humidity** (f_{abs}) is calculated by dividing the weight of the water (usually in g) contained in the air by the volume of the air quantity in question (usually in m^3).
- That’s why the absolute humidity is usually given in g per m^3.

Absolute air humidity: $f_{abs} = \frac{mass\ water\ in\ g}{volume\ of\ humid\ air\ in\ m^3}$

- The **relative humidity** describes the ratio of the current actual moisture contained in the air to the maximum possible absolute humidity.
- That's why relative humidity RH is always given in percent.
- **Relative air humidity:** $RH = \frac{actual\ absolute\ humidity\ in\ g/m^3}{maximum\ possible\ humidity\ in\ g/m^3}$ x $100\ \%$
- **Example 2:** (the sponge of the previous page) $RH = \frac{2.4\ g/m^3}{17.3\ g/m^3} x\ 100\ \% = 13{,}9\ \%$
- The capacity of air to absorb humidity is dependent on the air temperature. The warmer the air, the more water it can absorb.
- This relationship is shown in the chart:



Example 2 (sponge):
f_{abs} = 2,4 g/m³
T = 20 °C
RH = 14 %

Example 3: From the table one can see, that the maximum water content at 100 % RH of air at 30 °C is 30.4 g/m³ (= f_{max}).

This is the so called absolute air humidity f_{abs} or in this case, because it is the maximum possible water content air can hold, it is called f_{max}

Example 4: How much water holds 1 m³ of air at 30 °C and 60 % RH inside the kiln? f_{abs} = 30.4 g/m³ x 60 % = 18.2 g/m³

Temperature in °C	Max. water con-tent at 100 % RH f_{max} in g/m³ air
-10	2.31
-5	3.37
0	4.89
5	6.82

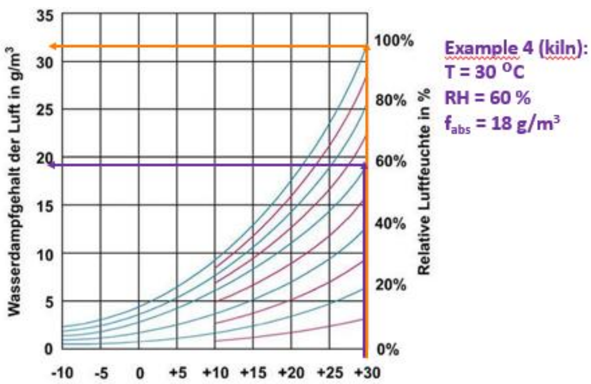
10	9.39
15	12.8
20	17.3
30	30.4
40	51.1
50	83.0
60	130
70	
80	

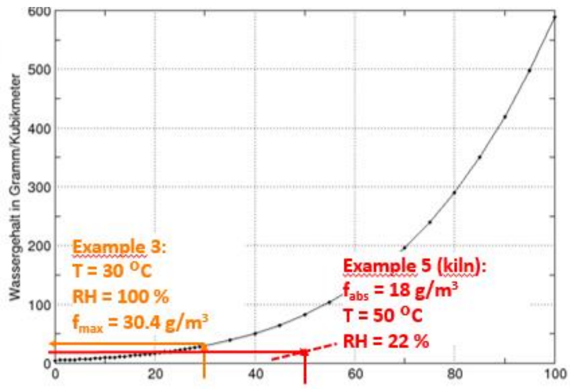
Example 5: If this air in the kiln is heated up to 50 °C and no moisture (no spray) is added, what will be the relative humidity?

$$RH = \frac{actual\ absolute\ humidity\ in\ g/m^3}{maximum\ possible\ humidity\ in\ g/m^3} \text{ x } 100\ \% = \frac{18.2\ g/m^3}{83.0\ g/m^3} x\ 100\ \%$$

$$= 21.9\ \%$$

Note: If the temperature rises, the relative humidity drops (at the same water content)! If the temperature drops, the relative humidity increases (at the same water content)!





- What is the water content f_{abs} of 1 m^3 of air in g/m^3 at
- RH = 100 % and T = 60 °C? …
- RH = 80 % and T = 60 °C? …
- RH = 60 % and T = 60 °C? …
- RH = 40 % and T = 60 °C? …
- RH = 80 % and T = 40 °C? …

- RH = 60 % and T = 40 °C? ...
- RH = 40 % and T = 40 °C? ...

M.C and EMC

- Usually, the primary guiding factor in operating a dryer is the MC of the lumber. The primary measure of the success of lumber drying is the final MC. Moisture can be measured with an oven and scales, where the wet piece is weighed, oven dried, and then reweighed.
- Or it can be measured with electronic moisture meters, which measure an electrical property of wood that is then correlated to MC. When the moisture content of the wood has reached equilibrium with its surrounding climatic conditions, it has reached its equilibrium moisture content (EMC):
- No moisture is given off and no moisture is taken on. The EMC of wood can be predicted by knowing the temperature and relative humidity conditions of the air in contact with the surface of the drying lumber.
- Example: At T = 20 °C and RH = 60 % the moisture content of wood will be approx. 11 (= EMC).

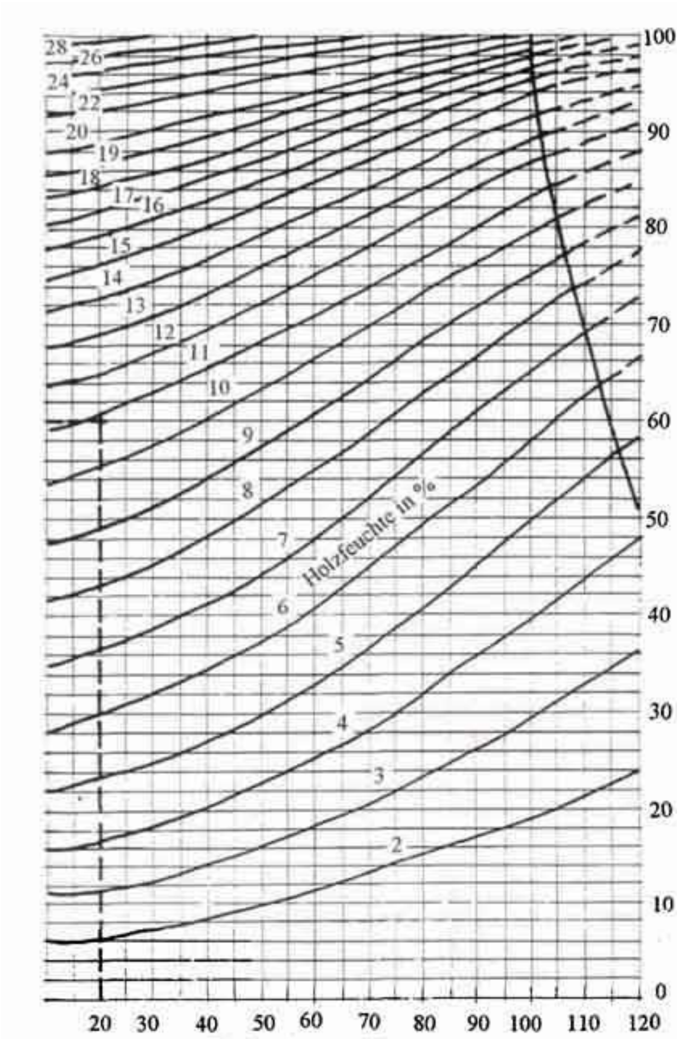


Table 4–2. Moisture content of wood in equilibrium with stated temperature and relative humidity

Temperature (°C	(°F))	Moisture content (%) at various relative humidity values 5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%
–1.1	(30)	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.4	13.5	14.9	16.5	18.5	21.0	24.3
4.4	(40)	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.3	13.5	14.9	16.5	18.5	21.0	24.3
10.0	(50)	1.4	2.6	3.6	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.3	11.2	12.3	13.4	14.8	16.4	18.4	20.9	24.3
15.6	(60)	1.3	2.5	3.6	4.6	5.4	6.2	7.0	7.8	8.6	9.4	10.2	11.1	12.1	13.3	14.6	16.2	18.2	20.7	24.1
21.1	(70)	1.3	2.5	3.5	4.5	5.4	6.2	6.9	7.7	8.5	9.2	10.1	11.0	12.0	13.1	14.4	16.0	17.9	20.5	23.9
26.7	(80)	1.3	2.4	3.5	4.4	5.3	6.1	6.8	7.6	8.3	9.1	9.9	10.8	11.7	12.9	14.2	15.7	17.7	20.2	23.6
32.2	(90)	1.2	2.3	3.4	4.3	5.1	5.9	6.7	7.4	8.1	8.9	9.7	10.5	11.5	12.6	13.9	15.4	17.3	19.8	23.3
37.8	(100)	1.2	2.3	3.3	4.2	5.0	5.8	6.5	7.2	7.9	8.7	9.5	10.3	11.2	12.3	13.6	15.1	17.0	19.5	22.9
43.3	(110)	1.1	2.2	3.2	4.0	4.9	5.6	6.3	7.0	7.7	8.4	9.2	10.0	11.0	12.0	13.2	14.7	16.6	19.1	22.4
48.9	(120)	1.1	2.1	3.0	3.9	4.7	5.4	6.1	6.8	7.5	8.2	8.9	9.7	10.6	11.7	12.9	14.4	16.2	18.6	22.0
54.4	(130)	1.0	2.0	2.9	3.7	4.5	5.2	5.9	6.6	7.2	7.9	8.7	9.4	10.3	11.3	12.5	14.0	15.8	18.2	21.5
60.0	(140)	0.9	1.9	2.8	3.6	4.3	5.0	5.7	6.3	7.0	7.7	8.4	9.1	10.0	11.0	12.1	13.6	15.3	17.7	21.0
65.6	(150)	0.9	1.8	2.6	3.4	4.1	4.8	5.5	6.1	6.7	7.4	8.1	8.8	9.7	10.6	11.8	13.1	14.9	17.2	20.4
71.1	(160)	0.8	1.6	2.4	3.2	3.9	4.6	5.2	5.8	6.4	7.1	7.8	8.5	9.3	10.3	11.4	12.7	14.4	16.7	19.9
76.7	(170)	0.7	1.5	2.3	3.0	3.7	4.3	4.9	5.6	6.2	6.8	7.4	8.2	9.0	9.9	11.0	12.3	14.0	16.2	19.3
82.2	(180)	0.7	1.4	2.1	2.8	3.5	4.1	4.7	5.3	5.9	6.5	7.1	7.8	8.6	9.5	10.5	11.8	13.5	15.7	18.7
87.8	(190)	0.6	1.3	1.9	2.6	3.2	3.8	4.4	5.0	5.5	6.1	6.8	7.5	8.2	9.1	10.1	11.4	13.0	15.1	18.1
93.3	(200)	0.5	1.1	1.7	2.4	3.0	3.5	4.1	4.6	5.2	5.8	6.4	7.1	7.8	8.7	9.7	10.9	12.5	14.6	17.5
98.9	(210)	0.5	1.0	1.6	2.1	2.7	3.2	3.8	4.3	4.9	5.4	6.0	6.7	7.4	8.3	9.2	10.4	12.0	14.0	16.9
104.4	(220)	0.4	0.9	1.4	1.9	2.4	2.9	3.4	3.9	4.5	5.0	5.6	6.3	7.0	7.8	8.8	9.9			
110.0	(230)	0.3	0.8	1.2	1.6	2.1	2.6	3.1	3.6	4.2	4.7	5.3	6.0	6.7						
115.6	(240)	0.3	0.6	0.9	1.3	1.7	2.1	2.6	3.1	3.5	4.1	4.6								
121.1	(250)	0.2	0.4	0.7	1.0	1.3	1.7	2.1	2.5	2.9										
126.7	(260)	0.2	0.3	0.5	0.7	0.9	1.1	1.4												
132.2	(270)	0.1	0.1	0.2	0.3	0.4	0.4													

Air circulation

An effective air flow inside the kiln is decisive for good, fast and even drying results.

Depending on the wood species, in the early stages of drying, high air velocities (more than 600 ft/min = 180 m/min = 3 m/s) can accelerate drying. In the late stages, low velocities (250 ft/min = 75 m/min = 1.3 m/s) are as effective as high velocities and use less energy.

2.4.4 Kiln types

After natural air drying of lumber, technical (or industrial) drying of lumber is applied to bring further down the moisture content, using various designs of dry kilns, e.g. batch kilns (continually take in fresh air and exhaust humid air) track loading kilns, continuous kilns, dehumidifier kilns, solar heated kilns, and vacuum dryers.

The kiln designs differ in size and equipment, e.g. source of heat and mechanism of heat supply, arrangement and type of fans and vents, measuring and control of relative humidity, applying of drying schedules (e.g. by PLC), how to measure the moisture content (MC and EMC), how to measure and control the air flow, how the transportation systems work, and use of various materials for construction of the kiln.

Batch or compartment kilns

Compartment-type kilns are designed for a batch process in which the kiln is completely loaded with lumber in one operation, and the lumber remains stationary during the entire drying cycle.

Temperature and relative humidity are kept as uniform as possible throughout the kiln.

All modern dry kilns use some type of forced-air circulation system, usually with air moving through the load perpendicular to the length of the lumber.

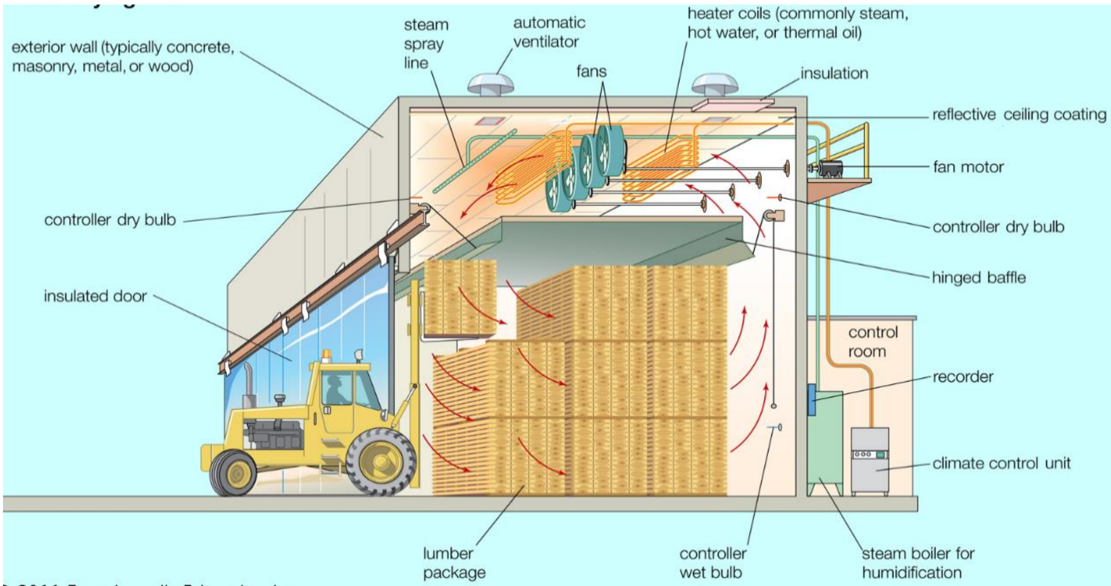


Fig 11: Batch or compartment kilns

Track loading kilns

The lumber is stacked on kiln trucks that are rolled into and out of the kiln on tracks.

Track-loaded kilns commonly have one or two sets of tracks and occasionally three sets, and are known as single-, double-, or triple-track kilns, respectively. The majority of the softwood lumber in the US is dried in track-loaded kilns and hardwood lumber is dried in package-loaded kilns (or side-loaded kilns).

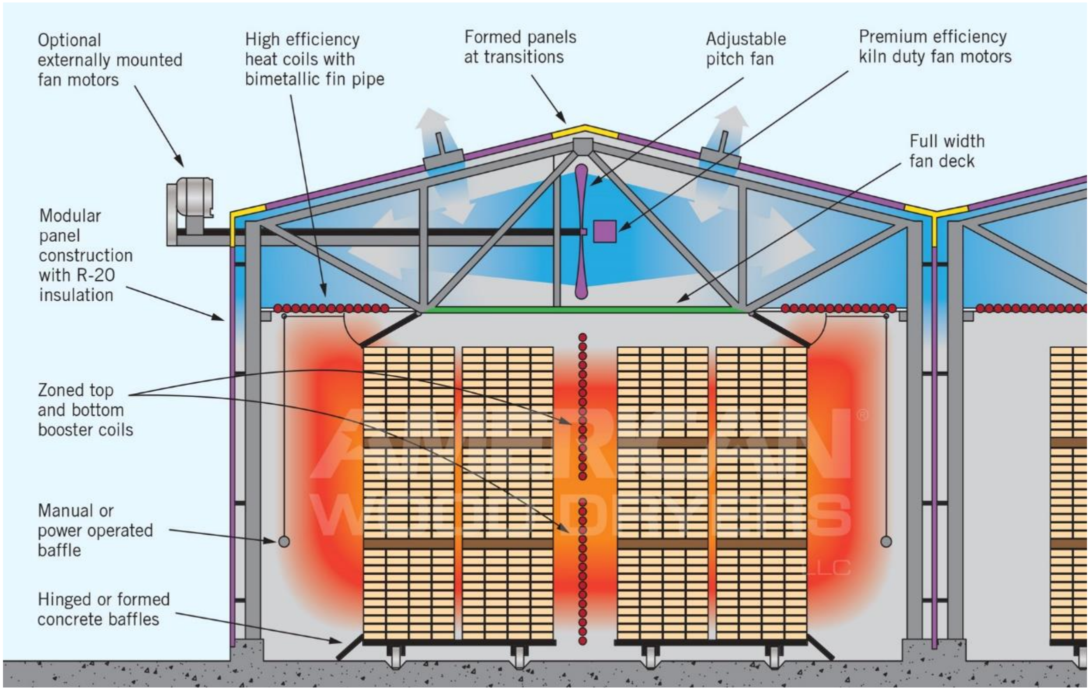


Figure 18: Track loading kilns

Continuous kilns

By a continuous process, in which the loads of stacked lumber enter the green end and are moved forward until exiting the dry end of the kiln, softwood is dried. Each move forward is accompanied by the removal of a completed load from the dry end and the addition of a fresh green load at the green end. The temperature increases and the humidity decreases as charges move from one zone to the next along the length of the kiln.

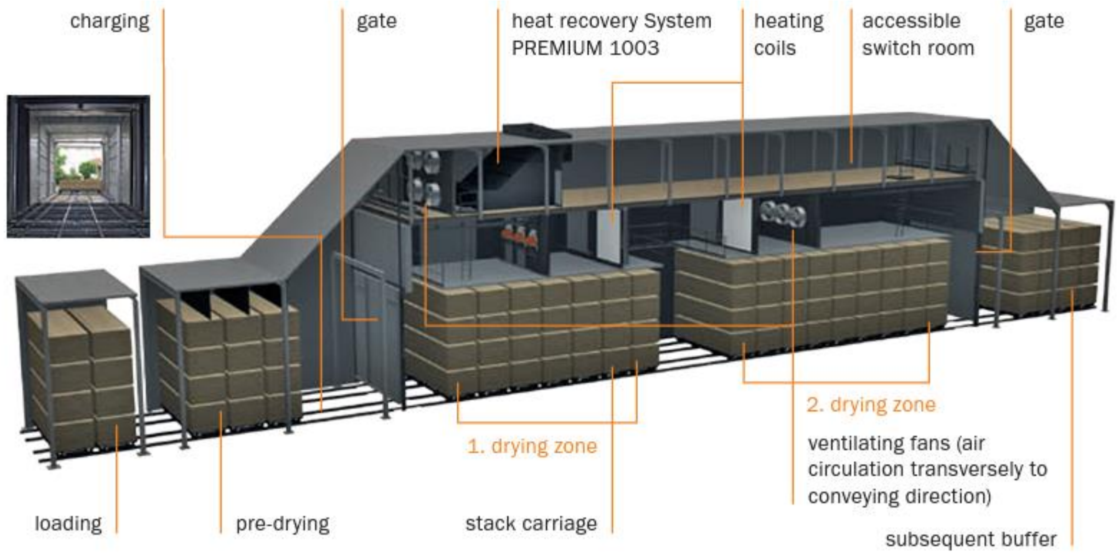


Figure 19: Continuous kilns

Vacuum dryers (VD)

In vacuum dryers the air pressure is reduced in order to reduce the boiling point of water. The boiling point of water is reduced from 100 °C to approx. 40 to 60 °C.

Because of the lower temperature, timber dries faster, drying stress is reduced, preventing warp, cracks, oxidation and discoloration (in hardwoods).

VD give high flexibility and quick responsiveness. Heat is supplied by air (at reduced speed), heating platens, radio frequency or superheated steam.

Solar heated kilns

Solar powered units use directly or indirectly the sun’s energy to provide the heat to dry the timber inside the kiln (chamber).

They are used for (pre-) drying either from green to fibre saturation point or from green to a target moisture content.

They have a low capital cost compared with conventional kilns, and low operating costs, as the heating energy is free.

The major drawback is that the energy of the sun varies with the time of day, different latitudes, with climate, and the seasons.

Figure 20: solar kiln

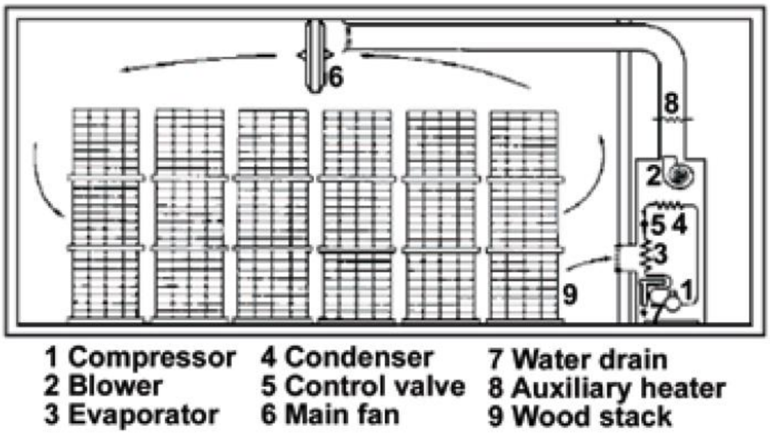
Solar heated kilns

Figure 21: Solar heated kilns

Dehumidifier (DH) kilns

For the Rwandan wood processing sector and small workshops, especially the DH kiln looks promising, because of its low capital costs, low requirements regarding the qualification of the operators, and the possibility to combine it with photovoltaic panels for the production of electricity needed for the fans, the compressor and the controls.

Whether or not an additional (electrical) heating is necessary has not yet been tested under Rwandan circumstances.



The dehumidifier works likes an air conditioner except the dehumidifier has both its hot and cold coils inside.

A fan draws the warm moist air into the unit and the moisture condenses on the cold coils. The condensation drips through a hose to a drain outside.

The second set of coils warms the cool dry air. The warm, dry air is pumped into the kiln to absorb more moisture from the lumber.

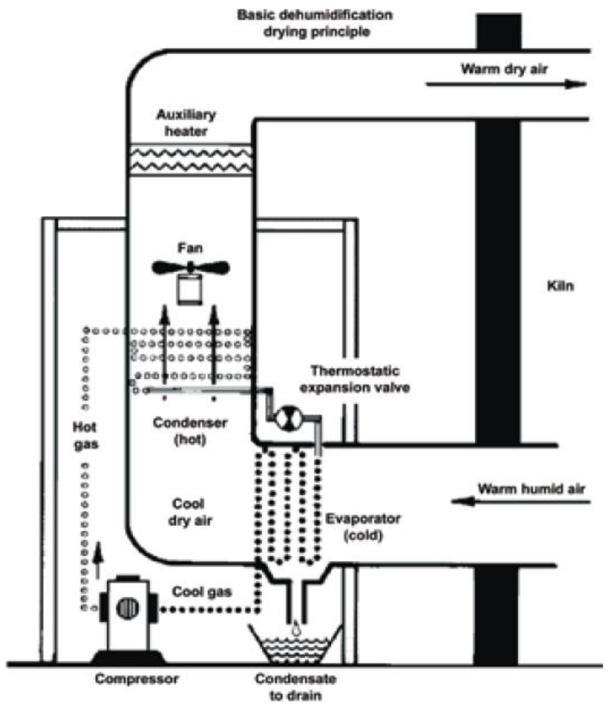


Figure 22: Dehumidifier (DH) kilns

Recommendations from 4 test runs of FPL laboratory kiln described in the research note "Operation and Cost of a Small Dehumidification Dry Kiln":

Suggested dehumidifier compressor sizing was 1 hp per 1,000 bft of mixed hardwoods (0.75 kW per 2.4 m3; Wengert and others 1988). Building and operating small dehumidification dry kilns give wood-workers greater control and flexibility of the drying process and the entire manufacturing process.

Figure 4—Front view of the dehumidification dry kiln (empty) with main doors on the side.

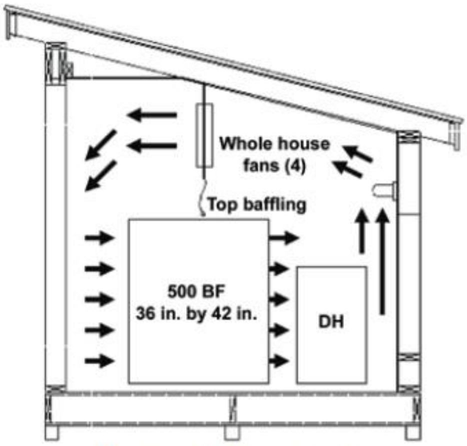


Figure 5—Side view of dry kiln indicating air direction and location of major components. DH is dehumidification.

Daily monitoring of the dry kiln is a must. The primary drying defect was casehardening; relieving casehardening after kiln drying therefore is vital to producing high-quality lumber.

Also, custom drying typically cost US$ 300 per 1,000 bft in the U.S. (according to Dr. Gene Wengert). Therefore, preferred uses for this kiln are drying small quantities of a select species and working with custom material.

Figure 6—Dehumidification dry kiln loaded with air-dried mixed hardwood and softwood.

Figure 7—Dehumidification dry kiln loaded with green mixed hardwood (four fans are shown, because two were added).

Patterns for self-build kilns

LD800 Drying Chamber (Fig 4)

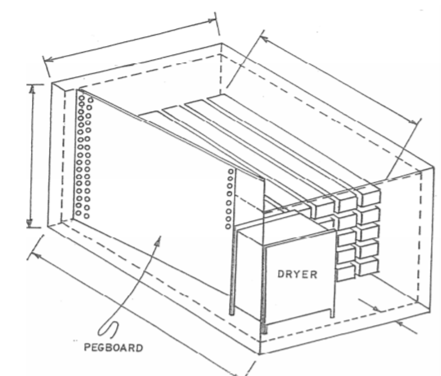
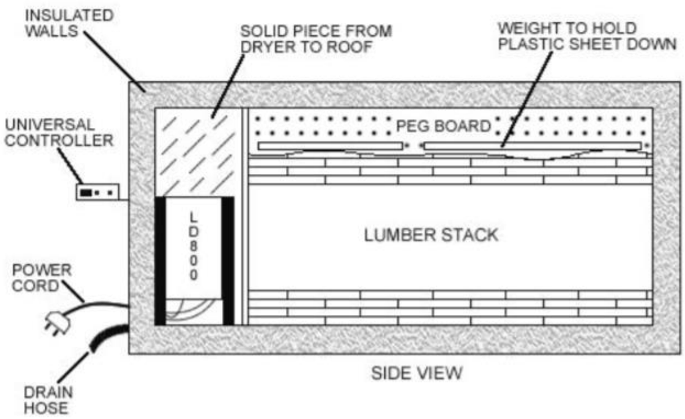


FIG 4

Lumber Stack Side View (Fig 5)



SIDE VIEW

Figure 23: Patterns for self-build kilns

MF4

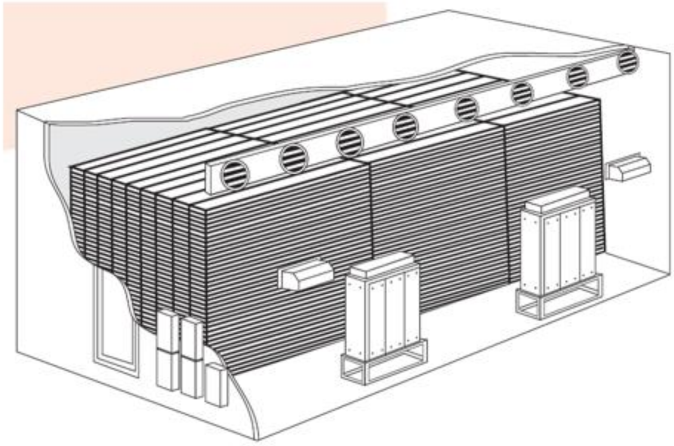
Product Data

Specification | Features | Accessories | Documents

	Part Number	
	1330700	1333000
	MF4	MF4
Height (inch)	61.0	61.0
Width (inch)	44.0	44.0
Depth (inch)	18.5	18.5
Weight(lbs)	418	418
Voltage	220	460
Phase	3	3
Frequency(Hz)	60	60
Drying Power(kW)	7.5	7.5
Heating Power(kW)	9.0	9.0
Total Power(kW)	16.5	16.5
Current(A)	42	42
Airflow(cfm)	3,500	3,500
Max OperatingTemp (°F)	140	140
Drying Capacities		
1" Hardwood (BF)		10,000
2" Hardwood (BF)		17,0000
3" Hardwood (BF)		28,900
1" Softwood (BF)		5,000
2" Softwood (BF)		12,000
3" Softwood (BF)		19,200

Optimum Capacity

The normal rated capacity of the MF4 when drying 1" hardwood is 10,000BF (8,400 cu ft). The units can be installed singularly or in multiples to provide drying capacity to match any need. The MF4 units are rugged, reliable wood drying systems designed for the larger wood retailer or sawmill needing regular supplies of thoroughly dried wood with minimal delay. The units can be installed singularly or in multiples to provide drying capacity to match any need.



MF2

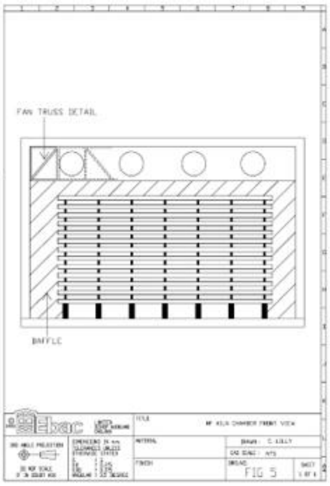
Product Data

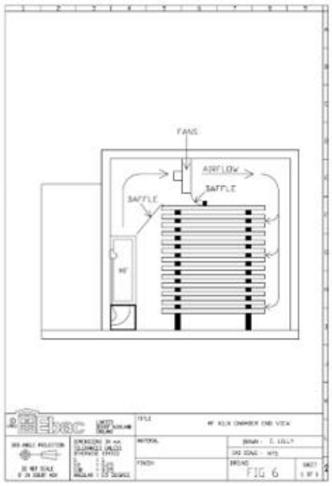
Specification | Features | Accessories | Documents

	Part Number	
	1320900	1331000
	MF2	MF2
Height (inch)	48.0	48.0
Width (inch)	44.0	44.0
Depth (inch)	18.5	18.5
Weight(lbs)	281	281
Voltage	220	220
Phase	1	3
Frequency(Hz)	60	60
Drying Power(kW)	3.5	3.5
Heating Power(kW)	4.5	4.5
Total Power(kW)	8.0	8.0
Current(A)	30	30
Airflow(cfm)	1,750	1,750
Max OperatingTemp (°F)	140	140
Drying Capacities		
1" Hardwood (BF)	5,000	5,000
2" Hardwood (BF)	8,600	8,600
3" Hardwood (BF)	17,792	17,792
1" Softwood (BF)	2,500	2,500
2" Softwood (BF)	5,600	5,600
3" Softwood (BF)	9,300	9,300

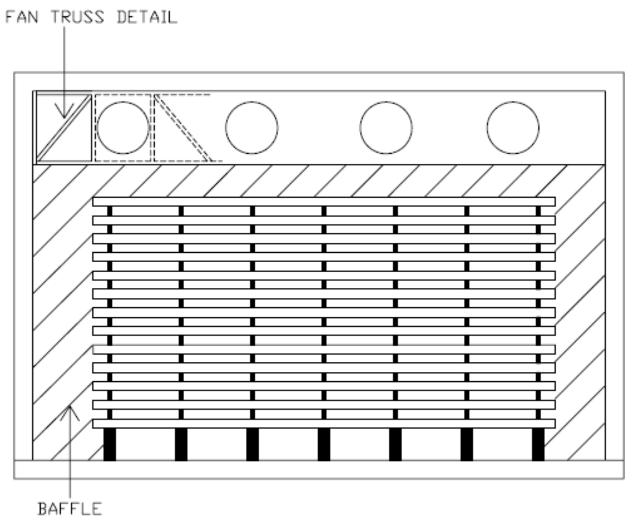
Optimum Capacity

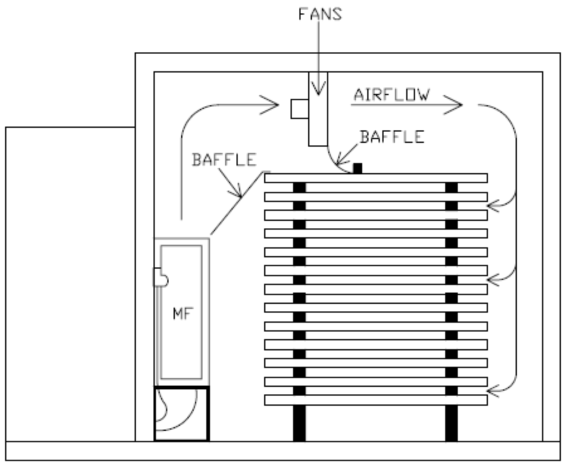
The normal rated capacity of the MF2 when drying 1" hardwood is 5,000BF (420 cu ft). The units can be installed singularly or in multiples to provide drying capacity to match any need. The MF2 units are rugged, reliable wood drying systems designed for the larger wood retailer or sawmill needing regular supplies of thoroughly dried wood with minimal delay. The units can be installed singularly or in multiples to provide drying capacity to match any need.





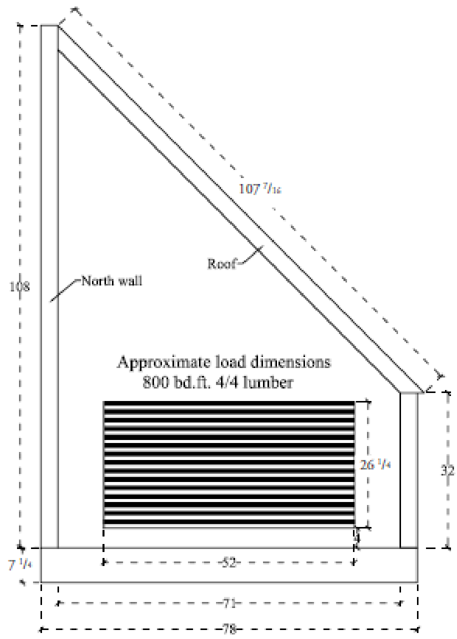
Small, complete dehumidification dry kilns are not available for sale and therefore the enclosure must be built individually.



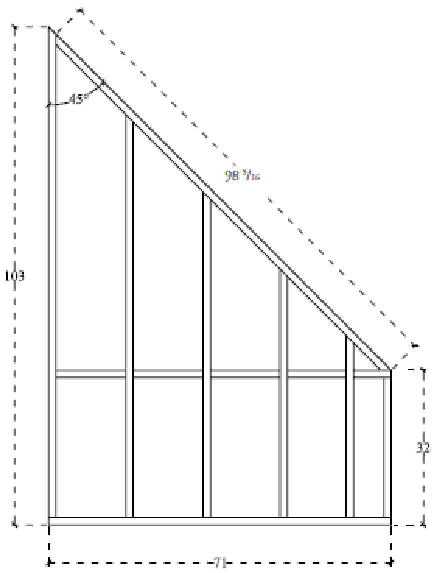


This construction plan is for an 800 board-foot capacity (1.9 cbm) dry kiln structure that is designed to work with an EBAC LD800TM dehumidification unit.

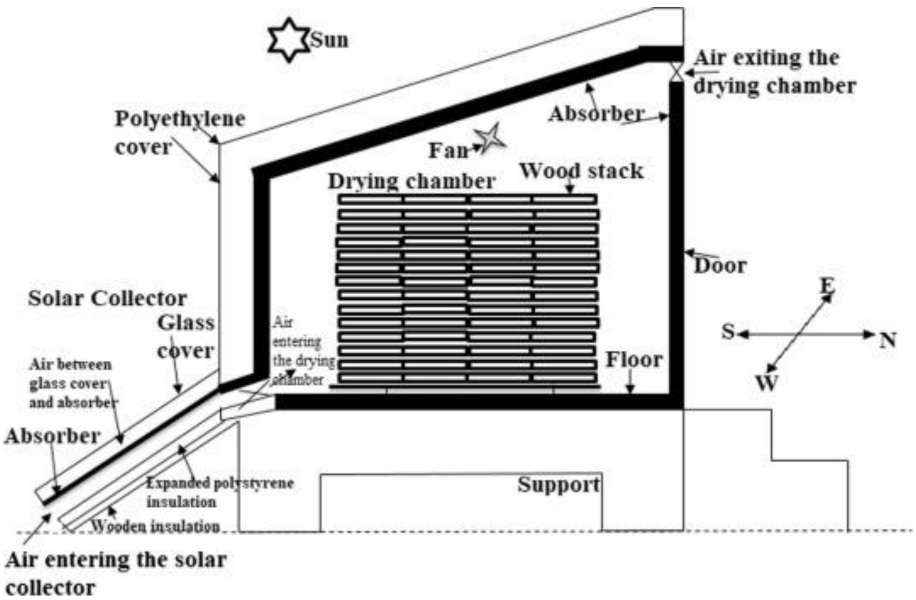
Features and Specifications	
Load Capacity	For softwoods and fast drying hardwoods (Pine or Poplar) 300BF For slow drying hardwoods (Oak) 1000BF.
Nominal Water Removal	60 lbs per 24 hours
Drying Time	4/4 Green Pine 80% to 8% in approximately 12 days. 4/4 Green Oak from 65% to 8% in approximately 35 days.
Operating Costs	Green Pine 80% to 10-12%, app. 350 kWh per 1000 board feet Green Oak 65% to 6%, app. 450 kWh per 1000 board feet.
Operating Temperature Range	70°-120°F (21°-49°C)
Pitch Setting Capabilities	Auxiliary heater can be used to set the pitch, sterilize the load (kill bugs) and for preheating.
Compressor Nominal HP	½ HP
Internal Blower Motors	2 internal fans, 50 watts each, 700 CFM
Auxiliary Heat	1,000 watts
Over Temperature Vents	Two manual vents included
Power Requirements	110 V. 60 Hz
Shipping Weight	175 pounds
Warranty	One year on material and workmanship. Contact Nyle for a full copy of the Warrenty.
Dimensions (H x L x W)	37 ½" x 22" x 14 ½"



Lateral view



East and west wall frames. 2x4 nominal studs



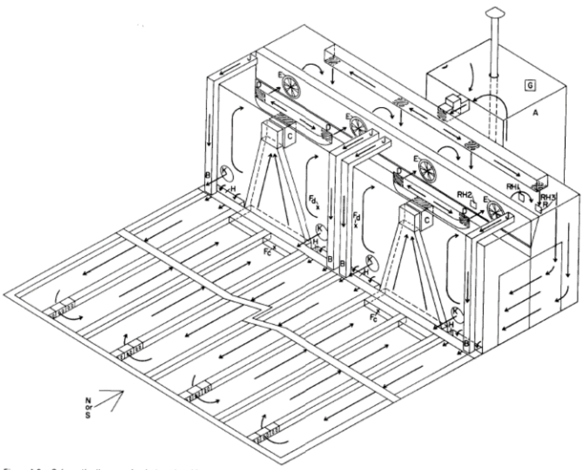


Figure A-2.—Schematic diagram of solarlwood residue dry kiln: (A) Furnace room; (B) Intake air enters collector; (C) Solar blower; (D) Manifold ducts for solar-heated air; (E) Internal fans; (F_c) Differential temperature sensor - collector; (F_d) Differential temperature sensor - dryer; (G) Humidifier; (H) Return air duct from dryer to collector (dampered); (J) Entry point of intake air; (K) Exhaust vents; (RH1) Humidistat (for exhaust vents K); (RH2) Humidistat (for shutting off kiln at high humidity); (RH3) Humidistat (for humidifier G). (ML845651)

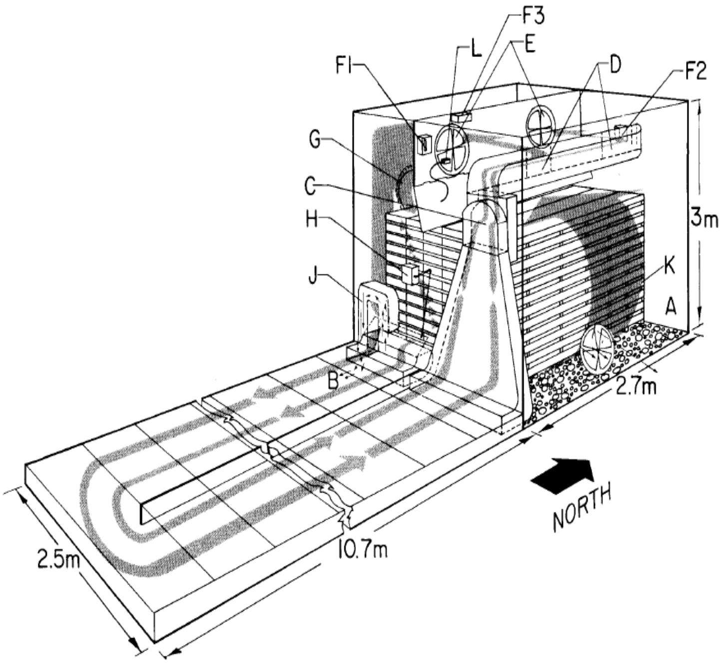
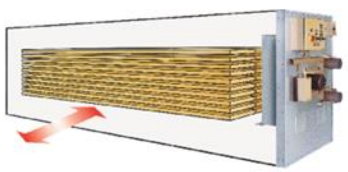


Figure A-1.—Schematic of solar dry kiln: (A) Drying chamber; (B) Solar collector; (C) Blower to induce air flow through the collector; (D) Hot air discharge to internal fans; (E) Internal fans; (F1) Humidistat for ventilator; (F2) Humidistat for upper limit control; (F3) Humidistat for humidifier; (G) Disk humidifier; (H) Damper motor for dryer-collector interchange or isolation; (J) Fresh air intake; (K) Power exhaust; (L) Thermostat. (M152098)

LAUBER Schrank

2 S–4	330 x 90 x 85	2,5	450 x 135 x 155	6,0	0,75
2 S–5	430 x 90 x 85	3,3	550 x 135 x 155	6,0	0,75
2 S–6	530 x 90 x 85	4,1	650 x 135 x 155	7,5	0,75
2 S–7	630 x 90 x 85	4,9	750 x 135 x 155	7,5	0,75
3 S–5	430 x 115 x 105	5,2	560 x 160 x 180	12,0	1,5
3 S–6	530 x 115 x 105	6,4	660 x 160 x 180	12,0	1,5
3 S–7	630 x 115 x 105	7,6	760 x 160 x 180	15,0	1,5

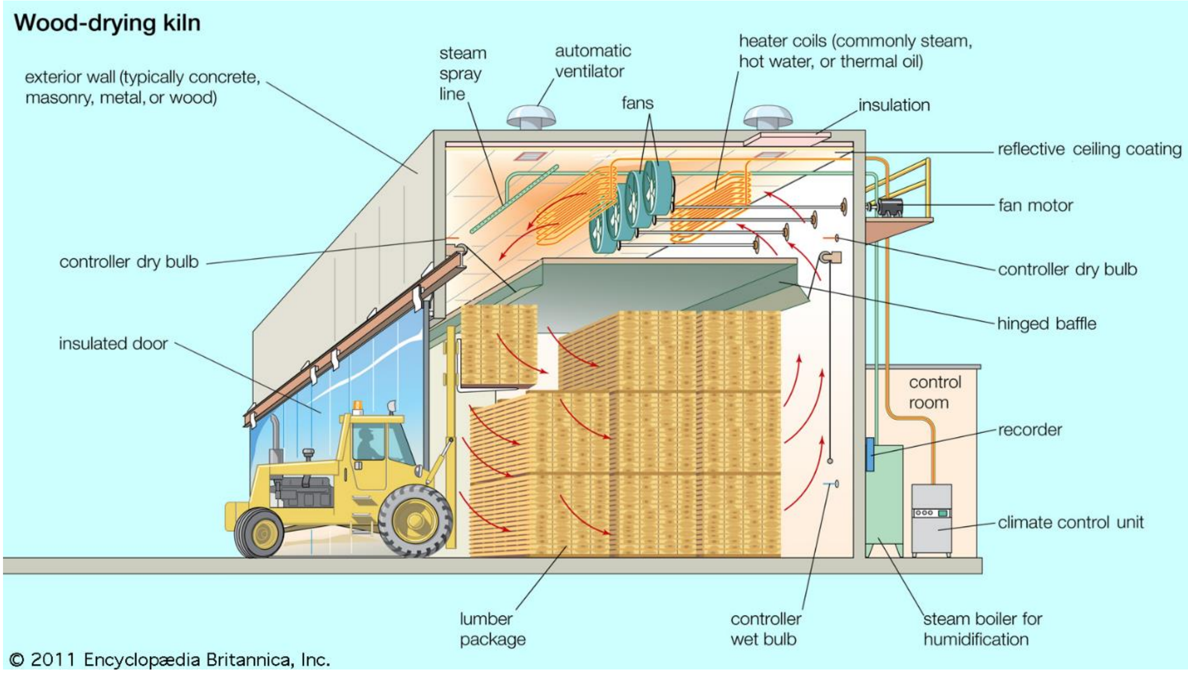


Selbstbau-Aggregat (AG)

2 S–AG	90 x 85			6,0	0,75
3 S–AG	115 x 105			12,0	1,1

Braun	T1 Standard	T1 Super	T2 Standard	T2 Super
Net volume of lumber	2.5 m^3	2.5 m^3	7 m^3	7 m^3
Condensed water per 24 hours	max. 12 liter	max. 16 liter	max. 70 liter	max. 80 liter
Power supply	0.3 kW 230 V, 50 Hz	0.97 kW 230 V, 50 Hz	0.88 kW 400 V, 50 Hz	3.5 kW 400 V, 50 Hz
Additional electrical heating	without	with	without	with
Weight	32 kg	33 kg	88 kg	90 kg
Size	700 x 350 x 400 mm	700 x 350 x 400 mm	650 x 660 x 1080 mm	650 x 660 x 1080 mm
Price net ex works (in 2020)	3,980.00 Euro	4,380.00 Euro	7,450.00 Euro	8,230.00 Euro

2.4.5 Kiln components



2.4.6 Sources of heat

Most dry kilns are designed to operate within a certain range of temperatures. This range depends largely on the species to be dried and quality and end use of final products. A common classification of kilns based on maximum operating temperatures is as follows:

- Low-temperature kiln 70...120 °F (20...50 °C)
- Conventional-temperature kiln 110...180 °F (45...80 °C)
- Elevated-temperature kiln 110...211 °F (45...100 °C)
- High-temperature kiln 230...280 °F (110...140 °C)

The type of heating of dry kilns and its energy sources for that heat can be divided into the following categories:

- Steam,
- Direct fire (burning fuel or gas to produce hot air),
- Electricity,
- Hot water,
- Hot oil,
- And solar (solar thermal energy, not photovoltaics)

Hot Water

Some kilns are heated by hot water rather than steam. These systems have much lower drying efficiency and are not commonly found in typical commercial operations. However, hot water heating systems are sometimes found in smaller homemade or do-it-yourself installations where steam generation is regarded as either impractical or too expensive.

Steam

Steam has long been the most widely used heating medium for kiln drying of lumber. Steam is moved from the boiler into the kiln by pipes, and the heat is then transferred to the circulating air in the kiln. Historically, many lumber processing operations required steam for a variety of applications, and it was therefore natural to include sufficient boiler capacity for kiln-drying operations. With the increasing popularity of electrically powered sawmills, the dry kilns are frequently the principal user of steam at an installation. In the early days of dry kilns, burning of wood waste in the boiler was the standard procedure. As oil and natural gas became more available and less expensive, most operations switched to these energy sources for their boilers. Since the "oil scare" and rising prices of the 1970's, there has been a return to burning of wood waste to generate steam. A more detailed discussion of

The drying of lumber requires the removal of large quantities of water from the wood. Since the heat for evaporation of water from wood is approx. 1 to 2 kWh/kg water, great quantities of heat energy must be generated and transferred to the circulating air and to the wood in the drying process; for more exact values see next page.

Energy requirements for evaporation of 1 kg of water

Drying method	kWh/kg
Batch kilns (fresh air exhaust air system)	
Hardwood, from green to dry	1.0 … 1.7
Hardwood, from FSP to dry	1.5 … 2.2
Softwood, from green to dry	0.7 … 1.0
Softwood, from FSP to dry	1.0 … 1.7
Vacuum kilns	0.7 … 3.0
Dehumidifier kilns	0.35 … 1.2

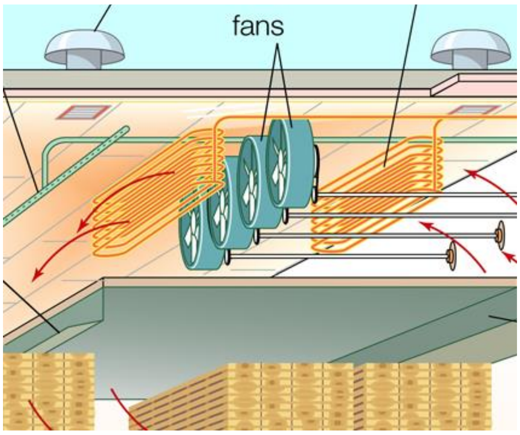
➢ The principal methods of conducting heat into the kiln

The principal methods of conducting heat into the Kiln are either:

- Indirect, where a hot fluid (steam, hot water or hot oil) flows into the kiln through pipes and radiates heat to the kiln atmosphere through a suitable radiating surface (assisted by ventilators), or
- Direct, where hot gases from the burner or boiler are discharged directly into the kiln atmosphere.

➢ Fans, vents and baffles

- In modern kilns, fans can be classified in two broad categories: internal fan kilns, that is, fans located inside the kiln itself; and external blower kilns, where the fan or blower is located outside the kiln and the air is conducted into the kiln through ducts.
- Internal fans are typically placed overhead, with a false ceiling or deck between the fans and the load of timber but not extending.



➢ Fans

Traditionally, kilns have been designed such that fan speeds and thus the velocity of air through the load of lumber do not change during the time of the kiln run.

However, for the most efficient drying, higher airspeeds are needed during the early stages of drying when the wood is wet and large quantities of water need to be evaporated. Later in the drying schedule, lower airspeeds are adequate as the wood becomes drier and less moisture needs to be evaporated.

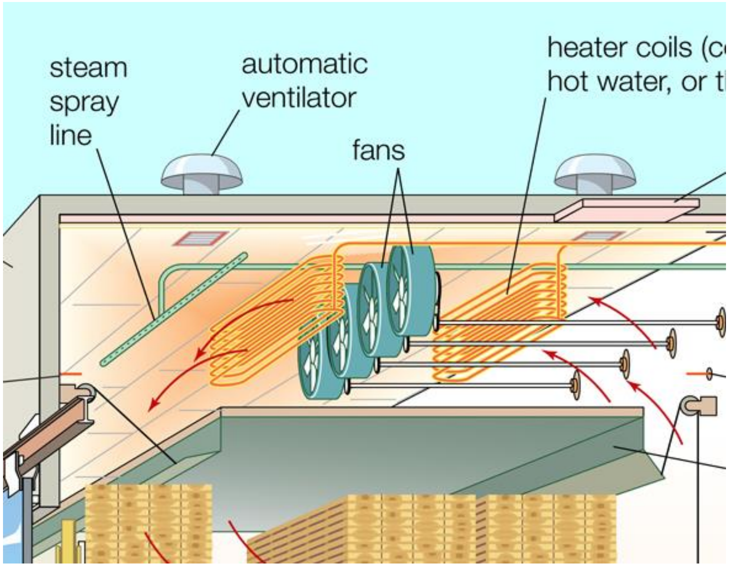
As electrical energy costs have increased, there has been increasing interest in installing control equipment on fan motors so that fan speeds can be adjusted during the run thus saving on energy costs and fan direction can be altered, too.

➢ Vents

Excess kiln moisture can be vented in one of two ways:

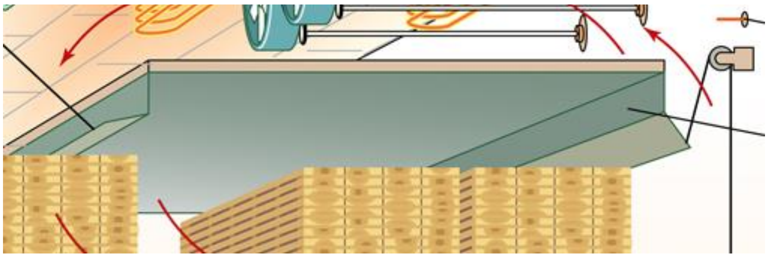
- By pressure venting with an additional fan, or
- By static venting, using the fans which are doing the air circulation in the kiln.
- In static venting, vents are placed in the roof on the intake and exhaust sides of the fans.

- When the vents are opened, fresh air is drawn in on the suction side of the fan and moist air forced out on the pressure side.



➢ Baffles

- A real effort should be made to construct all kiln loads so that no holes or gaps occur between stacks because of mixed lumber lengths or stacks of uneven height.
- To achieve uniform and rapid drying, the air must be uniformly directed to and through the timber stacks.
- To do this effectively, all alternate flow paths must be blocked so that airflow over, under, and around the load is prevented (no "shortcuts"!).
- The best way to do this is by using hinged baffles.

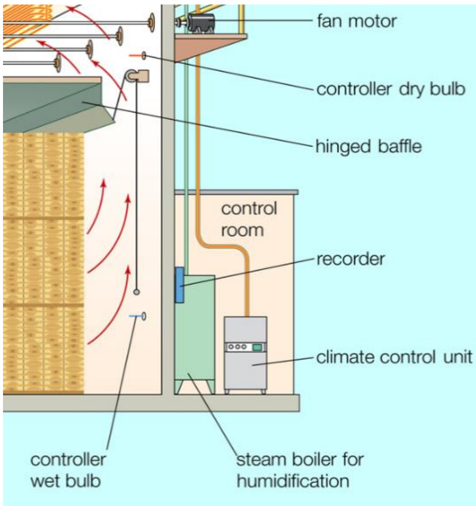


- Airflow under the load in a track-loaded kiln may be prevented by having baffles hinged to the floor that can be turned up against the kiln trucks to prevent air bypassing under the load.
- The use of ceiling-hinged baffles arranged so their lower free edge rests on the top of the load is an effective way of preventing airflow over the top of the load. As the load shrinks during drying, the baffles must have the ability to move down to keep contact with the load.
- Airflow around the ends of the load can be prevented by mounting bifold-hinged baffles in or near kiln corners, ensuring contact with the ends or corners of the load.

➢ Relative humidity (RH) and temperature (T)

To follow standardized kiln schedules with manual or automatic controls requires continuous information about T and RH inside the kiln. There are two approaches to obtain this information:

- Using dry bulb and wet bulb (thermometers), which one will not find in a new kiln anymore, or nowadays
- Using electronic sensors to measure the temperature and relative humidity, either as single sensors or combined RH/T-sensors.



Applying of drying schedules

While drying conditions in most commercial dry kilns are controlled by automatic or semiautomatic controllers, manual control is sometimes used in smaller kilns, but all of them **follow a specific drying schedule!**

Semiautomatic systems record and control on set points, changed from time to time manually by an operator.

In fully automatic systems, process control information is entered at the start of the kiln run, and any needed changes are made automatically by the PLC/computer.

One can manually or automatically set T and RH values according to the drying schedule **or** the so called drying gradient (DG) can be used to control the drying process:

- The drying gradient (DG) is the ratio of the moisture content (MC) compared to the equilibrium moisture content (EMC as determined by the climate settings of T and RH); DG = MC / EMC.

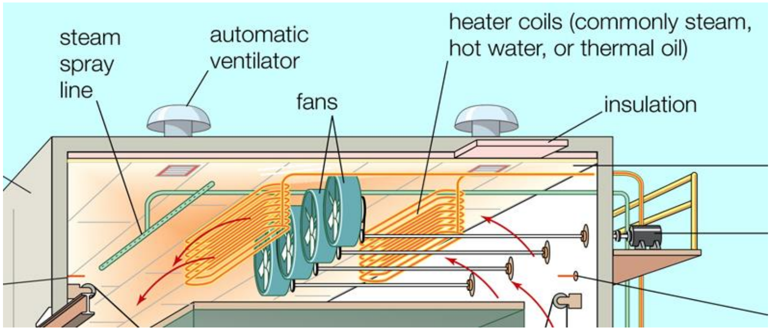
- Normal values of the DG vary from 2 to 4.
- The higher the drying gradient the faster the drying.

Step	Moisture content	Temperature Dry-bulb	Temperature Wet-bulb	Equilibrium moisture content	Relative humidity	Temperature Dry-bulb	Temperature Wet-bulb
	pct	°F	°F	pct	pct	°C	°C
1	Above 40	160	150	11.6	77	71.0	65.5
2	40 to 35	160	146	9.7	69	71.0	63.5
3	35 to 30	160	140	7.9	59	71.0	60.0
4	30 to 25	170	145	6.6	52	76.5	62.5
5	25 to 20	170	140	5.7	45	76.5	60.0
6	20 to 15	180	145	5.0	41	82.0	62.5
7	15 to Final	180	130	3.5	26	82.0	54.5

➢ Spraying equipment

Control of relative humidity (RH) in the kiln is important during the drying, equalizing, and conditioning stages of the drying operation. When RH is lower than desired, additional moisture can be added in two ways:

- Humidity is supplied as steam spray from the same source that supplies the heating coils, or
- Using water sprays (when there is no steam available), injected into the kiln in the form of a fine mist (what is usually assisted by compressed air).



➢ Measure the moisture content (MC and EMC)

- MC **either** can be measured manually by preparing kiln samples, remove them from the kiln periodically and weigh them for MC estimates (oven dry method) or using electrodes that are inserted into sample boards to measure electrical resistance as an estimate of MC.
- EMC either can be calculated according to the climate conditions **or** one can use an EMC-Probe inside the kiln (like a piece of veneer or paper) for measuring its electrical resistance as an estimate of its MC.

➢ Measure and control the air flow

- The proper design and use of the plenum space is necessary for adequate and uniform air circulation.
- The plenum chamber is the space between the timber stack and the door or wall in a package-loaded kiln.
- This area provides space for the fans to build up slight air pressure before passing through the courses of lumber thereby improving the uniformity of air distribution through the load. When the fans reverse direction, the positive pressure reverses sides, too.
- The plenum chambers should be wide enough so that the static pressure built up in them is sufficient to ensure uniform air flow across the loads from bottom to top.
- A frequently heard rule-of-thumb for estimating plenum width is that the width of the plenum should be equal to the sum of the sticker openings.
- Thus, if the sum of the sticker openings from top to bottom on one side of the load is 60 inch, the plenum on that side should be about 60 inch wide.
- A properly designed and loaded kiln will have adequate plenum space. It would be a mistake in loading package kilns to put an extra row of packages in what should be the plenum space on the door side.
- An effective air flow inside the kiln is decisive for good and even drying results.
- Depending on the wood species, in the early stages of drying, high air velocities (more than 600 ft/min = 180 m/min = 3 m/s) can accelerate drying.
- In the late stages, low velocities (250 ft/min = 75 m/min = 1.3 m/s) are as effective as high velocities and use less energy.
- Therefore, adjust fan speeds during a run if possible.

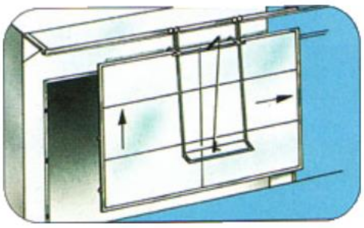
➢ Construction materials

- Dry kilns might be constructed from different materials:
- Prefabricated (insulated) aluminium (sandwich) panels, together with a supporting steel structure
- Concrete block, poured concrete, brickwork, masonry,
- Wood and plywood,
- And various kinds of vapor barriers are used to restrict movement of water vapor from inside the kiln into the structural members and panels and thus prevent deterioration of the structure.
- Dry kilns might be constructed from different materials:

- Prefabricated (insulated) aluminium (sandwich) panels, together with a supporting steel structure
- Concrete block, poured concrete, brickwork, masonry,
- Wood and plywood,
- And various kinds of vapor barriers are used to restrict movement of water vapor from inside the kiln into the structural members and panels and thus prevent deterioration of the structure.
- Because aluminum is extremely resistant to corrosion, no special vapor sealants or moisture barriers are required.
- However, regular inspections are needed to ensure that no leaks develop in the joints, and any punctures or tears in the skin of the panel need to be repaired to prevent moisture from the kiln atmosphere passing through to the insulation and reducing its effectiveness.
- If a steel supporting structure is used, usual precautions of applying a good paint or sealer must be observed to protect the steel from the corrosive atmosphere found in most kiln environments.
- To have acceptable efficiency, kilns must be reason-ably well insulated against loss of heat through the structure.
- In addition, doors and other openings must fit tightly to minimize loss of heat and humidity.
- At the same time the walls on the inside have to be sturdy enough against mechanical damage which can be done by forklift or be (collapsing) stacks of timber.
- Foundation footings and walls are almost always made of concrete. Their width is determined by the character of the soil and by the loads to be imposed upon them.
- Most kiln floors are made of poured concrete, usually 6 inch (15 cm) thick.
- Placing some form of insulation under the concrete floor reduces heat loss and helps to prevent condensation of water on the kiln floor in the early part of the kiln run when the relative humidity of the air is high and the floor may be cold.

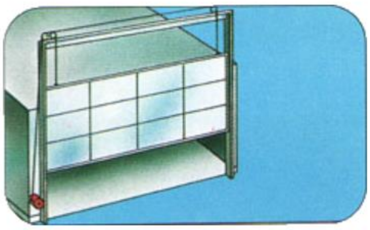
➢ Kiln doors

- Kiln doors are made of similar lightweight, insulated, aluminum panel construction like the walls, mounted in a steel or aluminum frame.
- Most doors are moved by hangers, which are connected to rollers operating on a rail over the door opening.
- Some type of flexible gasket is generally used around the opening to minimize air infiltration and leakage.



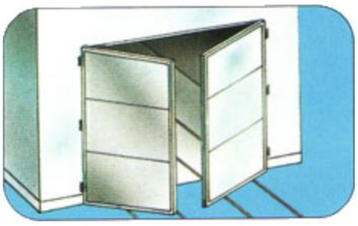
LIFTING-SLIDING DOOR

Manual or power operated, suitable for multi kiln installations. Excellent sealing is achieved by using the weight of the door.



HOIST LIFTED DOORS

Used for large kiln opening up to width of 46' (14 m). Operated either manually or by power winch. Includes a safety drop device. This door design is also suitable for progressive dry kilns.



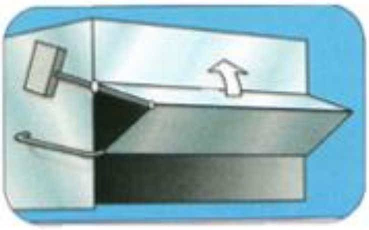
SWINGING DOOR

One or two panel, simple and economical, up to 19' (6 m) door width.

DOOR

FOLDING DOOR

Three to six sections. Inexpensive solution for large kiln widths. Equally suitably for front and side loaded kilns. Manually operated.



LIFTING-FOLDING DOOR

Excellent for installations where space is critical. Door operates with the help of a counter weight and is counter balanced in all positions.

SLIDING DOOR

Space saved in open position. Easy to move and operate manually.

2.4.7 Running a kiln

➢ Timber stacking and loading of a kiln

Ideally, lumber should be segregated based on all the factors that affect drying rate and quality, and it should be dried in uniform loads.

From the standpoint of drying quality, lumber must always be sorted by species and nominal thickness:

- Sorting on the basis of species tends to increase the efficiency of the drying operation because species differ in their drying characteristics.
- Thickness is also a basis for sorting because drying time depends on lumber thickness. As a general rule, 8/4 lumber (8/4-in.- (50.8-mm-) thick) requires about three times more drying time than does 4/4 lumber.
- Another reason for a thickness sort is stacking restraint, which helps control warp. If thick and thin boards are stacked in the same layer, the thin boards will not make contact with the stickers and therefore will not be restrained from warping.
- Sorting by length is strongly encouraged because it helps to decrease warp and sticker damage, simplifies stacking, and increases kiln capacity.
- Lumber is also frequently sorted by grade, with the higher grade material receiving special attention to prevent any drying losses.
- One of the best methods for sorting is to stack lumber of a single length on kiln trucks or in straight packages.
- If the stickers are well supported and in good alignment, such stacking results in flatter and straighter lumber.
- Overhanging ends of longer boards in a truckload of mixed-length lumber are likely to warp during drying.
- However, for stacking random lengths use box piling.

For almost all drying processes lumber must be stacked in horizontal layers, with each layer separated from the next by strips of wood called stickers. The importance of proper stacking cannot be overemphasized.

The major purposes of stacking lumber in a specified manner are to promote uniform air circulation, which in turn results in good drying; and to reduce or eliminate warp.

During stacking, the lumber may also be graded and measured for volume. Quality assessment of the lumber can be (in fact, should be) made at this point. Proper stacking prevents stacks from tipping over and thus is a matter of safety, too!

Sticker thickness is an important variable in drying, affecting drying speed and uniformity. Uniform thickness from sticker to sticker is also extremely important, since no uniform thicknesses will increase warp.

Typical sticker thickness for air drying is 3/4 in. (19 mm). For pre-drying and kiln drying, sticker thickness is usually 3/4 in. (19 mm), but 9/16- to 7/8-in. (14- to 22-mm) thicknesses are also used.

A properly designed kiln will work very well with 3/4-in. (19-mm) stickers.

Thicker stickers greatly reduce kiln capacity. As a rule of thumb, each 1/8-in. (3-mm) increase in sticker thickness reduces kiln capacity by 7%.

The stacking operation affords the opportunity to check the lumber for its conformity to various quality standards.

Typically, the grade and footage are verified, but other equally important factors should be checked, too:

- Color,
- Texture,
- Growth rate,
- Odor, and
- Moisture content.

Each kiln charge should consist of lumber with similar drying characteristics. Differences between boards will invariably exist despite measures to minimize them, and kiln sample selection must include these differences. The following variables should be considered in selecting kiln samples:

- Species,
- Thickness,
- Grain (flatsawn or quarter sawn; quarter sawn dries more slowly and with less cup),

- Moisture content, and
- Heartwood and sapwood.

Because these sorting practices frequently are not possible or practical, a kiln operator must be guided in the selection of kiln samples primarily by the drying rate of the most critical, slowest drying material.

The largest number of samples should be selected and cut from the slowest drying material.

Some samples should also be selected from the fastest drying material because these determine when the equalizing period should be started. The best time to select boards from which kiln samples will be cut, respectively for placing the electrodes, is during stacking.

Some samples are selected to represent the heavier, wetter, wider, and thicker lumber in the load; these samples contain a relatively high percentage of heartwood.

Some kiln samples are also selected from lumber that represents the drier and faster drying pieces. Such lumber is usually flatsawn, narrow, and thin, and it contains a high percentage of sapwood. Such pieces may also be drier than the rest of the lumber at the time of stacking or loading the kiln.

For optimum lumber quality, load the dry kiln according to the following suggestions:

Place stickers/bolsters on the kiln floor, perpendicular to the lengthwise direction of the lumber pile. Never place lumber directly on the floor.

Keep an appropriate distance to the walls, depending on the kiln's type of baffles and air circulation (see 2.4.6.2).

Always fill the kiln to its designed capacity. A smaller load than the designed size may dry more rapidly, perhaps leading to checking and honeycomb; air circulation might bypass the stack, thus the kiln runs not efficiently.

When placing some weights on top of the stack to prevent warp in the top layers, extensive care is needed to avoid a safety hazard!

Before each new load check the kiln whilst it is still empty according to the procedure described in lesson 2.4.8.7 “Maintenance”. When all the stacks are placed in the kiln:

- Connect the cables of the electrodes and check with the controls whether they are working properly and the value shown is realistic,
- Position the baffles or construct the baffles manually, and
- Select a suitable drying schedule for the kiln load, depending on species, thickness and initial moisture content.

➢ Dryings schedules

- A kiln schedule (or a drying schedule) is a series of temperatures and relative humidity that are applied at various stages of drying.
- In most schedules, the temperature is gradually increased and the relative humidity decreased.
- A kiln schedule is a carefully developed compromise between the need to dry lumber as fast as possible for economic efficiency and the need to avoid severe drying conditions that will lead to drying defects.

➢ Drying steps and stages

In some literature sources and manuals, the drying steps and phases are referred to as “drying regimes”:

- Heating regime (warmup)
- Capillary regime (stage I; MC > 30 %)
- Transition regime (stage II; 30 % > MC > 20 %
- Diffusion regime (stage III; 20 % > MC > final MC)
- Conditioning and equalizing regime (stage IV)
- Cooling regime

These six regimes describe a complete drying cycle in a batch kiln (fresh air/exhaust air).

➢ Manual programs

- The kiln operator follows the kiln schedule “manually” and has to adjust temperature and relative humidity of the kiln according to the schedule in regular intervals.
- Example of a very simple kiln schedule:

M.C. (%)	Temperature (°C) dry-bulb	Temperature (°C) wet-bulb	Air humidity (%)
Green	40	37	82
40	44	38	68
30	44	36	59
20	46	36	52
15	49	37	46

➢ Automatic programs

When using an automatic drying program, all the information of the drying schedule had been programmed into a PLC-based control system. With this the kiln runs automatically until the final MC is reached.

The computer system continually measures the temperature, (equilibrium) moisture content and relative humidity and adjusts the heating and the spraying system, the fans and vents according to the drying schedule.

➢ Drying of Eucalyptus SPP

The drying of Eucalyptus is known to be difficult:

Eucalypt wood generally dries slowly; surface checking, collapse and honeycombing limit the use of rapid drying or high temperature drying.

Heartwood often remains wet and water pockets are found in (otherwise) kiln dried Eucalyptus timber.

A large percentage of defects are caused by the presence of growth stresses in standing trees which become unbalanced upon felling or cross-cutting.

EUCALYPTUS GRANDIS

Page 2/4

SÉCHAGE

Vitesse de séchage : normale à lente
Risque de déformation : élevé
Risque de cémentation : oui
Risque de gerces : élevé
Risque de collapse : oui

Table de séchage suggérée : 1

Humidité bois (%)	Température (°C) sèche	Température (°C) humide	Humidité air (%)
Vert	40	37	82
40	44	38	68
30	44	36	59
20	46	36	52
15	49	37	46

Table donnée à titre indicatif pour des épaisseurs inférieures ou égales à 38 mm.
Elle est à valider par une mise en application dans le respect des règles de l'art.
Pour des épaisseurs comprises entre 38 et 75 mm, l'humidité relative de l'air serait à augmenter de 5% à chaque étape.
Pour des épaisseurs supérieures à 75 mm, l'augmentation serait de 10%.

Possible drying schedule: 1

M.C. (%)	Temperature (°C) dry-bulb	Temperature (°C) wet-bulb	Air humidity (%)
Green	40	37	82
40	44	38	68
30	44	36	59
20	46	36	52
15	49	37	46

Step	Moisture content	Temperature Dry-bulb	Temperature Wet-bulb	Equilibrium moisture content	Relative humidity	Temperature Dry-bulb	Temperature Wet-bulb
	pct	°F	°F	pct	pct	°C	°C
1	Above 50	120	116	17.6	88	49.0	46.5
2	50 to 40	120	115	16.3	85	49.0	46.0
3	40 to 35	120	112	13.5	77	49.0	44.5
4	35 to 30	120	106	9.9	62	49.0	41.0
5	30 to 25	130	100	5.7	35	54.5	37.5
6	25 to 20	140	90	2.9	15	60.0	32.0
7	20 to 15	150	100	3.2	18	65.5	37.5
8	15 to Final	180	130	3.5	26	82.0	54.5

Equalize and condition as necessary (see appendix A).

Step	Moisture content	Temperature Dry-bulb	Temperature Wet-bulb	Equilibrium moisture content	Relative humidity	Temperature Dry-bulb	Temperature Wet-bulb
	pct	°F	°F	pct	pct	°C	°C
1	Above 40	110	106	17.6	87	43.5	41.0
2	40 to 35	110	105	16.3	84	43.5	40.5
3	35 to 30	110	102	13.6	76	43.5	39.0
4	30 to 25	120	106	9.9	62	49.0	41.0
5	25 to 20	130	100	5.7	35	54.5	37.5
6	20 to 15	140	90	2.9	15	60.0	32.0
7	15 to Final	160	110	3.4	21	71.0	43.5

Equalize and condition as necessary (see appendix A).

Step	Moisture content	Temperature Dry-bulb	Temperature Wet-bulb	Equilibrium moisture content	Relative humidity	Temperature Dry-bulb	Temperature Wet-bulb
	pct	°F	°F	pct	pct	°C	°C
1	Above 40	110	107	19.1	90	43.5	41.5
2	40 to 36	110	106	17.6	87	43.5	41.0
3	35 to 30	110	104	15.2	81	43.5	40.0
4	30 to 25	120	110	12.1	72	49.0	43.5
5	25 to 20	130	105	6.7	43	54.5	40.5
6	20 toi 15	140	90	2.6	15	60.0	32.0
7	15 to Final	160	110	3.4	21	71.0	43.5

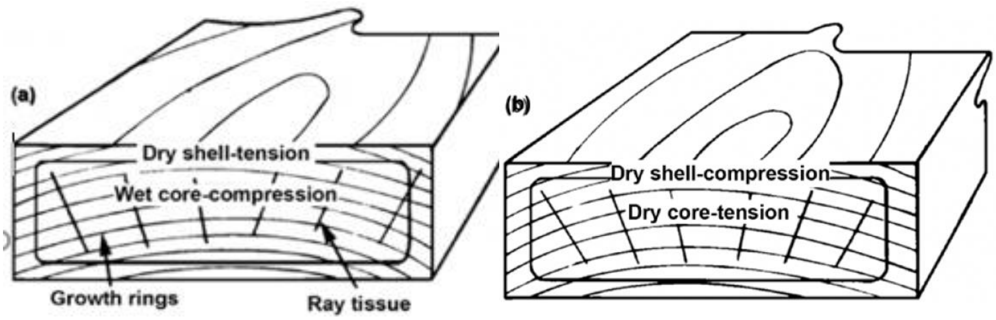
Equalize and condition as necessary (see appendix A).

➤ Drying stress

The cause of drying stresses is the differential shrinkage between the outer part of a board (the shell) and the interior part (the core):

Early in drying, the fibers in the shell dry first and begin to shrink. However, the core has not yet begun to dry and shrink; consequently, the core prevents the shell from shrinking fully.

Thus, the shell goes into tension and the core into compression (a).



As drying progresses, the core begins to dry and attempts to shrink:

- However, the shell is set in a permanently expanded condition and prevents normal shrinkage of the core.

- This causes the stresses to reverse; the core goes into tension and the shell into compression (b).
- These internal tension stresses may be severe enough to cause internal cracks (honeycomb).

➢ Equalizing and conditioning

Equalizing treatments are used to reduce the MC spread within boards as well as between the wettest and driest boards in a kiln charge of lumber.

An equalizing treatment is suggested when the spread between the driest and the wettest kiln sample boards exceeds about 3 % MC in the final stages of drying. Conditioning treatments are used to relieve the drying stresses and tension set (casehardening) that are present at the end of kiln drying and equalizing.

➢ Data recording

Data recording has to be done either manually or the automatic control system will do it automatically.

Good recordkeeping of the details of kiln runs can be useful to the kiln operator in several ways:

- For modifying drying schedules on subsequent charges to obtain faster drying without sacrificing quality,
- For developing time schedules for certain types of lumber that are dried frequently,
- For determining the effect of seasonal weather conditions on kiln performance and drying time,
- For checking kiln performance for causes of no uniform drying or drying defects, and
- For following certain rules and regulations, e.g. Ispm 15.

➢ Data recording for ISPM 15 standard

Its main purpose is to prevent the spread of disease and insects that could negatively affect plants or ecosystems.

ISPM 15 affects all wood packaging material (pallets, crates, etc.) requiring that they be debarked and then heat treated or fumigated with methyl bromide and stamped or branded, with a mark of compliance.

If heat treatment (HT) is applied, the wood needs to be heated until its core reaches 56 °C for at least 30 minutes (what has to be recorded).

The kinds of data to be recorded will vary with the nature of the drying. More than the usual amount of drying data is required in the case of a test run in a new kiln, a new and unfamiliar type of lumber, and a new or modified schedule. Also, good documentation of the kiln run may be useful when precise drying is required.

The data can include lumber species, grade, origin (of both the lumber/sawmill) and the trees (geographical location) it was cut from), grain (flatsawn or quarter sawn), percentage of sapwood, number of rings per inch, moisture content, and thickness; date of sawing; intermediate handling between sawing and drying; drying data (initial), schedule, time, and defects; handling and storage after drying; shipping date.

- Many kiln operators develop their own forms to fit their specific needs.
- Drying data should be recorded for each sample respectively for each MC electrode.
- Other data (such as kiln number; lumber volume, species, and thickness; and starting and ending dates for the run) can be entered as required.
- Data for the final moisture and drying stress tests should also be recorded.
- The amount of casehardening present should be noted. Photocopying the stress samples is an easy method of recording casehardening levels.
- The sample data, stress sample data, and kiln chart should be saved for further reference.

A completed sample record is shown in figure 7.6, p. 72 of “Drying Hard-wood Lumber”, using kiln samples and the oven dry method to measure the moisture content.

KILN SAMPLE RECORD

SPECIES Red Oak THICKNESS or SIZE 4/4 KILN NO. 3

Date Run Started March 14 Hour 9 am Ended

SAMPLE NO.		MOISTURE SECTIONS WT. (G.)	MOISTURE SECTIONS O.D. WT. (G.)	GREEN WT. OF SAMPLE	CALC. O.D. WT.	DATE	3/14	3/15	3/16	3/17					REMARKS
						HOUR	9am	9am	9am	9am					
						TOTAL HRS or DAYS	0	1	2	3					
#11 A	WT.	257.32	201.64	2.462	1.910		2.462	2.396	2.345	2.302					
	M.C.	27.6		28.9			28.9	25.4	22.8	20.5					
B	WT.	269.45	206.91												
	M.C.	30.2													
	WT.														
	M.C.														
#12 A	WT.	375.82	275.97	1.450	1.052		1.450	1.402	1.376	1.340					
	M.C.	36.2		37.8			37.8	33.3	30.8	27.4					
B	WT.	351.17	251.80												
	M.C.	39.5													
	WT.														
	M.C.														
#13 A	WT.	277.66	211.66	1.832	1.392		1.832	1.802	1.758	1.720					
	M.C.	31.2		31.6			31.6	29.5	26.3	23.6					
B	WT.	265.46	200.89												
	M.C.	32.1													
	WT.														
	M.C.														
	WT.														
	M.C.														
	WT.														
	M.C.														
	WT.														
	M.C.														
	WT.														
	M.C.														
	WT.														
	M.C.														
AV. M.C. OF ALL SAMPLES							32.8	29.4	26.6	23.8					
AV. M.C. OF 2 WETTEST SAMPLES							34.7	31.4	28.6	25.5					

2.4.8 Troubleshooting and possible malfunctioning

➢ Control instruments

- When instruments are out of calibration, the actual
- Drying conditions differ from those recorded, and serious kiln-drying defects or increased drying time may result.
- Check calibration at two or three points over total range at the time of new installation. Thereafter, check it for accuracy frequently, e.g. by using thermometers.
- Repairs to electronic or computerized recorder controllers should be made only by an experienced technician or authorized serviceperson.

- For those instruments using air-actuated valves or pneumatic cylinders, the compressed air supply must be clean and protected from oil and moisture.
- For this reason, the air is passed through a filter drip well or trap before entering the instrument.
- The trapped oil or moisture is blown from the drip well or trap at least once daily by opening a blow off valve.
- Usually the elements in filters must be replaced once a year or more frequently if they become discolored.
- Dry kiln operators should be familiar with the manufacturer's instructions for the care and maintenance of recorder-controllers and all other control instruments.
- If the instrument should fail, trained service people should be contacted for advice and service.
- According to the advice of the manufacturer one should keep a few spare parts in stock, especially when the kiln is operated in remote places and when it takes a long time until a technician or s spare part will arrive.

➢ Electronic sensors

- First of all, T-, EMC- and RH-sensors (or other measuring instruments) need a proper location inside the kiln:
- The sensors must be mounted in the main airstream flowing in the plenum.
- The sensors should not be too close to the wall or to the timber stacks and not too close to steam pipes or other sources of heat that may give false readings.
- The sensors, its connectors and wires should not be mechanically damaged, corroded or covered with dust.

➢ Fans

The items to be checked in the periodical inspection of the air-circulation system include the following:

- Fan motors,
- Fan shafts,
- Pulleys and belts,
- Fans and fan blades (damage, direction, reverse),
- Baffles (top, floor and end baffles), and
- Oil lines and lubrication.

➢ Vents

- Vents are for exhausting hot, moist air from the kiln and taking in fresh air. Thus, excessive venting increases heating and humidification requirements, and it should be avoided by proper adjustment and maintenance:
- Inspect the vent lids or dampers when they are in a closed position;
- If necessary, install gaskets around vent openings to prevent leakage;
- Avoid over venting by adjusting the linkage so that the lids or dampers are open just wide enough to obtain the desired venting;
- Examine air lines or electric circuits connecting the vent mechanism to the control.

➢ Spraying

- Steam or water sprays supply moisture to the kiln atmosphere when required to maintain the desired relative humidity. Reasons which can lead to malfunctioning:
- Faulty manual or automatic valves have to repaired immediately;

- Inspect the steam or water spray line itself periodically to see that the discharge holes or nozzles are open and that the pipe has not been bent or turned so that the spray discharges onto the lumber or the instrument controls or sensors;
- Open plugged spray holes or nozzles and repair or replace damaged lines;
- When using steam for spraying, usually a small drain line discharging the condensate that collects at the low end outside the kiln; keep this drain line open.

➢ Heating and pumps

- A correctly designed and properly maintained heating system produces uniform drying conditions in a kiln. There are several reasons which can lead to malfunction:
- Improperly insulated feedlines,
- Leaking pipes and unions,
- Distorted pipes (because of failing supports),
- Faulty pumps or faulty automatic and manual valves,
- Inspect and maintain boilers and burners according to the manual of the manufacture

➢ Maintenance

Regular, systematic inspections and maintenance should cover such items as the kiln structure; doors; floor; tracks; control equipment; heating, spraying, and venting system; trucks; lumber-handling equipment; and general housekeeping.

To make sure that inspections are thorough, the operator should note the condition of the kiln structure and the equipment on a checklist (see chapter 4 of “Dry Kiln Operator’s Manual” page 100).

Appendix-
Kiln Inspection Checklist

(Where maintenance or replacement is recommended, indicate kiln number.)

I. Kiln Structure

1. **Doors and door hangers**, present condition:

   Do door hangers operate properly: ____________________

   Do doors fit properly: ____________________

   Do gaskets adequately seal door: ____________________

   What maintenance a replacement is recommended: ____________________

2. **Walls**, present condition:

   IS protective coating adequate (masonry kilns): ____________________

   Are cracks repaired or holes patched: ____________________

   What maintenance or replacement is recommended: ____________________

3. **Structural steel members**, present condition:

   Is protective coating adequate: ____________________

   What maintenance or replacement is recommended: ____________________

4. **Roof or ceiling**, present condition:

   Is protective coating adequate to minimize corrosion and vapor transmission: ____________________

   What maintenance or replacement is recommended: ____________________

5. **Floors and walkways**, present condition:

   What maintenance or replacement is recommended: ____________________

6. **Rails and supports**, present condition:

   What maintenance or replacement is recommended: ____________________

II. Control system

1. **Recorder-controller**, present condition:

   Is correct chart paper on instrument: ____________________

   Is recorder-controller properly calibrated: ____________________

   Are capillary tubes protected: ____________________

   Are leads and connections of RTD adequately protected: ____________________

   Are bulbs or sensors properly located and mounted for accurate reading of kiln conditions: ____________________

   Does cellulose EMC wafer need replacing: ____________________

   What maintenance or replacement is recommended: ____________________

2. **Water supply:**

   Is water supply line to wet bulb open: ____________________

   Is wet-bulb water pan clean: ____________________

   Is water supply unusually hot or cold: ____________________

   Is drain line from water pan open: ____________________

Is wet-bulb wick replaced regularly: ____________________

What maintenance or replacement is recommended: ____________________

3. **Air supply:**

Is compressed air supply at correct pressure, clean, and uninterrupted: ____________________

Is compressor in good condition: ____________________

Are water and grease traps in good condition: ____________________

What maintenance or replacement is recommended: ____________________

III. Heating and Humidifying System

1. **Steam feedlines and headers,** present condition:

Are feedlines and headers properly insulated: ____________________

What maintenance or replacement is recommended: ____________________

2. **Heating coils or ducts,** present condition:

Are all pipes open to full flow of steam: ____________________

What is the condition of supports: ____________________

Is ductwork bent or otherwise damaged: ____________________

What maintenance or replacement is recommended: ____________________

3. **Traps, present condition:**

Are traps in best possible location: ____________________

What maintenance or replacement is recommended: ____________________

4. **Condensate return line,** present condition:

Are condensate pumps working properly: ____________________

Is line properly sized for volume carried: ____________________

What maintenance or replacement is recommended: ____________________

5. **Automatic and manual control valves,** present condition:

Are automatic control valves working properly: ____________________

Are springs and diaphragms working properly: ____________________

Are manual blowdown-valves provided for traps: ____________________

Are manual valves provided for shutting off individual coils: ____________________

Are check valves working properly: ____________________

What maintenance or replacement is recommended: ____________________

6. **Spray lines,** present condition:

Are spray holes or nozzles open: ____________________

Does condensate from spray line drip on lumber: ____________________

Is spray line properly trapped: ____________________

What maintenance or replacement is recommended: ____________________

7. **Vents,** present condition:

Do all vents open and close properly: ____________________

Do air motors and linkages work properly: ____________________

What maintenance or replacement is recommended: ____________________

IV. Air Circulation System

1. **Fans and motors,** present condition:

   What is the condition of electrical connections and switches: ______

   Are fans slipping on shafts: ______

   Are all fans turning in proper (same) direction: ______

   What maintenance or replacement is recommended: ______

2. **Shafts and bearings,** present condition:

   Are motors and shaft bearings properly lubricated: ______

   What maintenance or replacement is recommended: ______

3. **Fan baffles, cowling, and fan floor,** present condition:

   What maintenance or replacement is recommended: ______

4. **Load baffles,** present condition:

   Can load baffles be improved: ______

   What maintenance or replacement is recommended: ______

5. **Air passageways (including ductwork in direct-fired kilns):**

   Are air passageways open and unobstructed: ______

   Could air movement be improved: ______

   What maintenance or replacement is recommended: ______

V. General Condition of Yard, Kilns, and Control Room

Does grading and surface of yard provide for good drainage directed away from kiln(s): ______

Are alleys adequate for maneuvering lift truck: ______

Are kiln trucks in good condition: ______

What maintenance or replacement is recommended: ______

Is control room neat and clean: ______

Are good kiln records kept: ______

Are kilns and surrounding area neat and clean: ______

➢ Maintenance of doors

Doors are frequently the weakest and most trouble-some part of a kiln structure. Neglect of doors and door equipment may also create a hazard to workers.

The doors have to be large, strong, lightweight, easy to handle, well insulated, close and tight, and resistant to corrosion.

They are often damaged when they are opened or closed carelessly, when a forklift operator does not pay attention when loading or unloading the kiln.

Immediately repair or replace damaged door hangers, rollers, and roller tracks. Lubricate parts in accordance with the manufacturer's recommendations.

Repair or replace torn or missing gaskets that no longer provide an adequate seal.

Instructor warn lift truck operators to be alert to minimizing damage to doors (also to walls and baffles) when loading or unloading the kiln.

In package-loaded kilns, ensure that piles are stable and will not tip over into doors or walls.

In track-loaded kilns, block wheels of standing loaded kiln trucks, so that the trucks cannot roll into the kiln door.

2.5. Development and application of drying schedules

2.5.1. Drying schedules

- A kiln schedule (or a drying schedule) is a series of temperatures and relative humidity that are applied at various stages of drying.
- In most schedules, the temperature is gradually increased and the relative humidity decreased, thus lowering the EMC.
- A kiln schedule is a carefully developed compromise between the need to dry lumber as fast as possible for economic efficiency and the need to avoid severe drying conditions that will lead to drying defects.

2.5.2 Drying schedules objectives

- Rapid drying is achieved by the use of temperatures as high as possible and relative humidity as low as possible to balance the highest drying rate with the avoidance of objectionable drying defects.
- The schedule must be developed in a way that the drying stresses do not exceed the strength of the wood at any given temperature and moisture content.
- Otherwise, the wood will crack either on the surface or internally or be crushed by forces that collapse the wood cells.

2.5.3 Development of drying schedules

- The development of drying schedules is more a matter of trial and error, experience of the dry kiln operator rather than a matter of pure science.
- For orientation one can use publications like the FPL General Technical Report 57 „Dry Kiln Schedules"

- Modern PLC controllers for dry kilns usually have a couple of in-built automatic programs from which the operator can choose.
- The technical principles behind those computers based programs are still the same as in the written charts.

2.5.4 MC- or time-controlled schedules

- Often hardwood lumber is dried by MC-schedules. This means that the temperature and relative humidity conditions are changed according to the moisture content of the lumber during drying.
- Therefore, some method of monitoring moisture content during drying is required for schedules based on moisture content.
- Softwood kilns might be run by a time-controlled schedules. Hereby, kiln temperature and relative humidity change at predetermined times.
- When using a MC-controlled schedule it is possible to apply the drying gradient (DG), what is of special interest when using computerized controls and automatic drying programs:
- The Drying Gradient (DG) is the ratio of the moisture content (MC) compared to the equilibrium moisture content (EMC as determined by the climate settings of T and RH); DG = MC / EMC.
- Normal values of the DG vary from 2 to 4.
- The higher the drying gradient the faster the drying.

Table 267

Step	Moisture content	Temperature Dry-bulb	Temperature Wet-bulb	Equilibrium moisture content	Relative humidity	Temperature Dry-bulb	Temperature Wet-bulb
	pct	°F	°F	pct	pct	°C	°C
1	Above 40	160	150	11.6	77	71.0	65.5
2	40 to 35	160	146	9.7	69	71.0	63.5
3	35 to 30	160	140	7.9	59	71.0	60.0
4	30 to 25	170	145	6.6	52	76.5	62.5
5	25 to 20	170	140	5.7	45	76.5	60.0
6	20 to 15	180	145	5.0	41	82.0	62.5
7	15 to Final	180	130	3.5	26	82.0	54.5

2.5.5 Warmup period

The time required for warmup vary from 1 to 24 h; warmup time is lengthened if:

- Lumber and kiln structure temperatures are low or lumber is frozen,
- Temperature of the outside air is low,
- Initial moisture content of the lumber is high,
- Lumber is thick,
- Density of the species is high,

- Heat losses through the kiln walls and roof are high,
- Seals around closed vents and doors are poor,
- Some heating coils are inactive, or boiler output is too low.

2.5.6 Drying stages

– Stage I

- At the start of drying, a fairly low temperature is required to maintain maximum strength in the fibers near the surface to help prevent surface checks.
- The RH should be kept high early in drying to minimize surface checking caused by tension stresses that develop in the outer shell of the lumber.
- Even under these mild initial kiln conditions, the lum-ber loses moisture rapidly. The drying rate is monitored to ensure that drying does not occur too rapidly.
- This part of the drying process is called **stage I**.

– Stage II

- After the loss of the first one-third of lumber MC (based on green MC), the drying rate begins to slow down. The mild drying conditions are no longer necessary because the surface fibers have little or no risk of checking at this point.
- That is, the wood fibers become stronger as MC decreases and can safely withstand higher drying stresses. Therefore, to maintain an acceptable drying rate, the RH is lowered gradually, starting at the one-third loss point. This is **stage II** drying.

– Stage III

- When the wood reaches 30 % average MC, in general the temperature can safely be raised gradually and the humidity can continually be lowered.
- These initial temperature changes must be gradual because of the danger of internal checking (often called honeycomb). This is **stage III** drying.
- As a rule of thumb, when the moisture in lumber at midthickness is below 25 % to 30 %, it is generally safe to make large increases (10 °F = 6 °C) in temperature to maintain a fast drying rate.
- For thicker lumber of some dense species and for squares, it may necessary to decrease average MC to 15 % to lower the mid-thickness MC to 25 %–30 %.

– Stage IV

- **Stage IV** involves equalizing and conditioning the lumber.
- Equalizing is the process of developing uniform MC within and between the individual pieces of lumber in a load.

- Conditioning is the process of relieving drying stresses.

2.5.7 Equalizing

- Equalizing treatments are used to reduce the MC spread within boards as well as between the wettest and driest boards in a kiln charge of lumber.
- An equalizing treatment is suggested when the spread between the driest and the wettest kiln sample boards exceeds about 3 % MC in the final stages of drying.
- Begin the equalizing treatment when the driest sample is 3 % below the final target MC and continue until the wettest piece has dried to the target MC.

Table A1 —Suggested equalization treatments for hardwoods and softwoods (equalizing at final target MC minus 3 pct MC)

Dry-bulb temperature	Wet—bulb temperature at final target moisture contents of				
	6 percent	7 percent	8 percent	9 percent	10 percent
			°F		
130	85	91	96	101	106
140	93	100	105	111	115
150	100	103	115	121	125
160	110	117	125	131	136
170	120	127	134	141	146
180	130	137	145	152	157
190	140	147	156	162	168
			°C		
54.5	29.5	32.5	35.5	38.5	41
60	33	37.5	40.5	43	46
65.5	37.5	39.5	46	49.5	51.5
71	43.5	47	51.5	55	57.5
76.5	48	52.5	56.5	60.5	63.5
82	54.5	58	62.5	66.5	69
87.5	60	64	69	72	75.5

2.5.8 Conditioning

Conditioning treatments are used to relieve the drying stresses and tension set (casehardening) that are present at the end of kiln drying and equalizing.

Any lumber that will be resawed, ripped, or machined non-uniformly should be conditioned to relieve stresses.

Failure to do so will result in warping (cupping, crooking, bowing, or twisting) during machining and will cause difficulty in boring.

The conditioning treatment should be the final step in kiln drying after reaching the target MC and completing the equalizing treatment.

Time can vary from 4 to 72 hours, depending on thick-ness of lumber, density of species, the speed with which the proper depression can be achieved, and the amount of stress relief required.

In general, more effective stress relief can be achieved in less time with thinner boards or lower density species than with thicker boards or denser species.

Table A2–Suggested conditioning (stress relief) treatments for hardwoods and softwoods[1] (conditioning at final target MC plus 4 pct MC)

Dry-bulb temperature	Wet-bulb temperatures at final target moisture content of –				
	6 percent	7 percent	8 percent	9 percent	10 percent
	°F				
140	126	128	130	132	133
150	136	138	140	142	143
160	146	149	151	152	154
170	157	159	161	163	164
180	168	170	171	173	174
190	178	180	182	183	185
200	188	190	193	194	195
	°C				
60	52	53	54.5	55.5	56
65.5	57.5	59	60	61	61.5
71	63.5	65	66	66.5	67.5
76.5	69	70.5	72	72.5	73
82	75.5	76.5	77	78.5	79
87.5	81	82	83	84	85
93	86.5	87.5	89	90	90.5

Evaluation of stress relief achieved is made by cutting stress sections, sometimes known as the “prong test”.

A final analysis for freedom from stress cannot be made until the test prongs have air-dried 16 to 24 hours, but a noticeable turning-out of the transverse test prongs immediately after they are cut often indicates that the transverse stresses have been relieved.

Good stress relief is commonly defined as straight or nearly straight prongs after the 16- to 24-hour drying period.

Two basic methods are used for preparing stress sections to identify casehardening. Both methods operate on the principle that transverse stress (= perpendicular to axial stress) will become unbalanced when lumber is sawn:

The first technique indicates whether stress is present and how severe it is.

The second technique provides a visual guide to the extent of moderate to severe stress.

The tables A1 and A2 recommend a certain dry-bulb and wet-bulb temperature (relative humidity) for equalization and conditioning.

Hypothesis: Since equalization is always necessary when the MC varies more than 3 % within the kiln load, conditioning might not be necessary because the final target MC in Rwanda usually is not set to 10 % (or below 10 % as shown in the tables A1 and A2) and therefore the drying stress might not be so high.

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SÉCHAGE

Vitesse de séchage : normale à lente
Risque de déformation : élevé
Risque de cémentation : oui
Risque de gerces : élevé
Risque de collapse : oui

Table de séchage suggérée : 1

Humidité bois (%)	Température (°C) sèche	Température (°C) humide	Humidité air (%)
Vert	40	37	82
40	44	38	68
30	44	36	59
20	46	36	52
15	49	37	46

Table donnée à titre indicatif pour des épaisseurs inférieures ou égales à 38 mm.
Elle est à valider par une mise en application dans le respect des règles de l'art.
Pour des épaisseurs comprises entre 38 et 75 mm, l'humidité relative de l'air serait à augmenter de 5% à chaque étape.
Pour des épaisseurs supérieures à 75 mm, l'augmentation serait de 10%.

Possible drying schedule: 1

M.C. (%)	Temperature (°C) dry-bulb	Temperature (°C) wet-bulb	Air humidity (%)
Green	40	37	82
40	44	38	68
30	44	36	59
20	46	36	52
15	49	37	46

2.5.9 Examples – Eucalyptus

- Drying schedules T6-D2, T3-C2 and T3-C1 for Eucalyptus were copied from Section IV Asian and Oceanian Woods of FPL-GTR "Dry Kiln Schedules"; please, mind its preface:
- Schedules in this section are gathered from the world literature. Because of the wide variation found within a species, these schedules are considered conservative.
- They are intended for use in steam-heated kilns operated between 110 and 195 °F (43 and 90 °C), with air speeds from 200 to 400 feet per minute (1 to 2 m/sec).

- Changes in instrument settings are generally on the basis of MC of the wood, and the use of sample boards is highly recommended (no time-controlled schedules).
- Schedules are listed for two thickness groups, 4/4 to 6/14 and 8/14 using U.S. schedule format, and for 4/4 to 6/14 stock by the British schedule.

2.5.10 Examples – Eucalyptus T6-D2

Step	Moisture content	Temperature Dry-bulb	Temperature Wet-bulb	Equilibrium moisture content	Relative humidity	Temperature Dry-bulb	Temperature Wet-bulb
	pct	- - - - - - °F - - - - - -		- - - - - pct - - - - - -		- - - - - - °C - - - - - -	
1	Above 50	120	116	17.6	88	49.0	46.5
2	50 to 40	120	115	16.3	85	49.0	46.0
3	40 to 35	120	112	13.5	77	49.0	44.5
4	35 to 30	120	106	9.9	62	49.0	41.0
5	30 to 25	130	100	5.7	35	54.5	37.5
6	25 to 20	140	90	2.9	15	60.0	32.0
7	20 to 15	150	100	3.2	18	65.5	37.5
8	15 to Final	180	130	3.5	26	82.0	54.5

Equalize and condition as necessary (see appendix A).

2.5.11. Examples – Eucalyptus T3-C2

Step	Moisture content	Temperature Dry-bulb	Temperature Wet-bulb	Equilibrium moisture content	Relative humidity	Temperature Dry-bulb	Temperature Wet-bulb
	pct	- - - - - - °F - - - - - -		- - - - - - pct - - - - - -		- - - - - - °C - - - - - -	
1	Above 40	110	106	17.6	87	43.5	41.0
2	40 to 35	110	105	16.3	84	43.5	40.5
3	35 to 30	110	102	13.6	76	43.5	39.0
4	30 to 25	120	106	9.9	62	49.0	41.0
5	25 to 20	130	100	5.7	35	54.5	37.5
6	20 to 15	140	90	2.9	15	60.0	32.0
7	15 to Final	160	110	3.4	21	71.0	43.5

Equalize and condition as necessary (see appendix A).

2.5.12. Examples – Eucalyptus T3-C1 (for 8/14)

Step	Moisture content	Temperature Dry-bulb	Temperature Wet-bulb	Equilibrium moisture content	Relative humidity	Temperature Dry-bulb	Temperature Wet-bulb
	pct	- - - - - - °F - - - - - -		- - - - - - pct - - - - - -		- - - - - - °C - - - - - -	
1	Above 40	110	107	19.1	90	43.5	41.5
2	40 to 36	110	106	17.6	87	43.5	41.0
3	35 to 30	110	104	15.2	81	43.5	40.0
4	30 to 25	120	110	12.1	72	49.0	43.5
5	25 to 20	130	105	6.7	43	54.5	40.5
6	20 toi 15	140	90	2.6	15	60.0	32.0
7	15 to Final	160	110	3.4	21	71.0	43.5

Equalize and condition as necessary (see appendix A).

2.6 Estimate timber drying cost

2.6.1 Wood species

- Some species of wood have markedly different drying characteristics than others (e.g. amount of water, applied temperature and energy needed).
- Thus, a milder drying schedule must be used to avoid drying defects in the more sensible wood species which increases drying time and drying costs.
- So, whenever possible and practical, a kiln charge should consist of the same species or of species with similar drying characteristics.
- Some species of wood have markedly different drying characteristics than others (e.g. amount of water, applied temperature and energy needed).
- Thus, a milder drying schedule must be used to avoid drying defects in the more sensible wood species which increases drying time and drying costs.
- So, whenever possible and practical, a kiln charge should consist of the same species or of species with similar drying characteristics.
- **Grain:** Flatsawn lumber generally dries faster than quarter sawn lumber, but it is more susceptible to such drying defects as surface checks, end checks, and honeycomb. Quarter sawn lumber may be segregated from flatsawn lumber and dried under severe kiln conditions, using a shortened drying time.
- **Grade:** Higher grade lumber is usually sorted out and kiln dried by different schedules than the lower grades (because of its higher strength, closer control of final moisture content and better appearance).

2.6.2 Timber moisture content

- It is not desirable to mix air-dried, partially air-dried, and green lumber in the same kiln charge.
- Wetter lumber requires milder initial drying conditions and longer drying time than drier lumber.
- The main purpose for air drying lumber is to evaporate as much water as possible while minimizing capital cost for dry-kiln capacity and energy cost.
- In air drying, lumber is usually left on stickers in the yard until it reaches a moisture content between 25 % and 30 %.

2.6.3 Timber size

- **Thickness:** Sorting for thickness is essential! Uniform thickness simplifies stacking and drying. It reduces warping. Another reason for sorting for thickness is the variation in drying time with thickness. Drying time is inversely related to thickness.

- **Length:** One of the best and easiest methods for sorting is to stack lumber of a single length in packages. If the stickers are well supported and in good alignment, such stacking results in flatter and straighter boards.

2.6.4 Fixed costs

- Fixed costs refer to expenses that a company must pay, independent of any specific business activities.
- These costs are set over a specified period of time and do not change with production levels.
- This means fixed costs are generally indirect, in that they don't apply to a company's production of any goods or services.
- Companies can generally have two types of costs –fixed or variable costs – which together result in their total costs.

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2.6.5 Variable costs

- A variable cost is an expense that changes in proportion to production output or sales.
- When production or sales increase, variable costs increase; when production or sales decrease, variable costs decrease.
- Variable costs stand in contrast to fixed costs, which do not change in proportion to production or sales volume.

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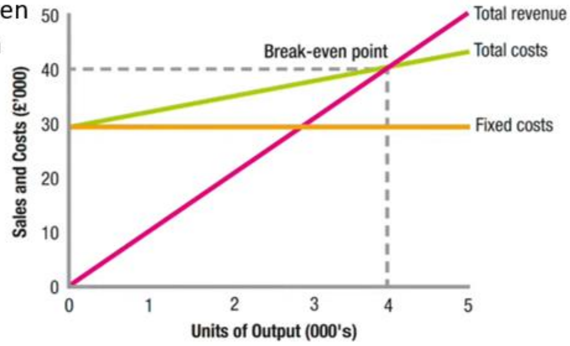
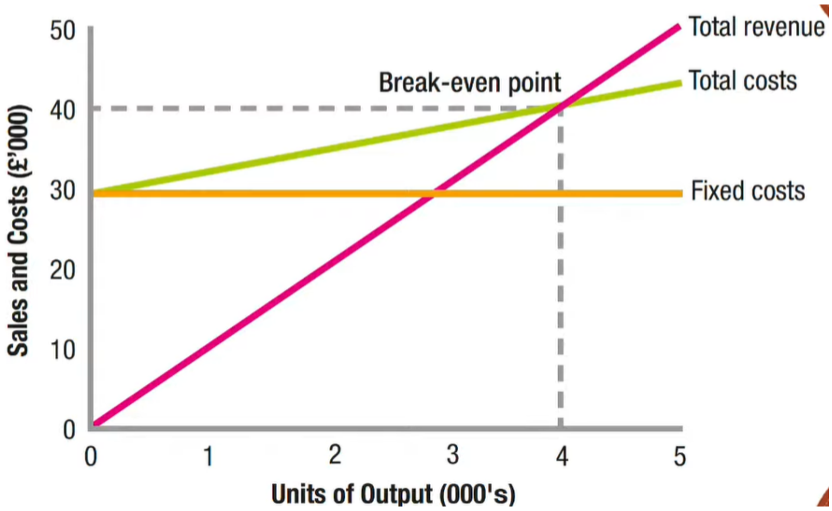
2.6.6 Cost benefit analysis (break-even analysis)

- Break-even analysis tells you how many units of a product must be sold to cover the fixed and variable costs of production.
- The break-even point is considered a measure of the margin of safety.

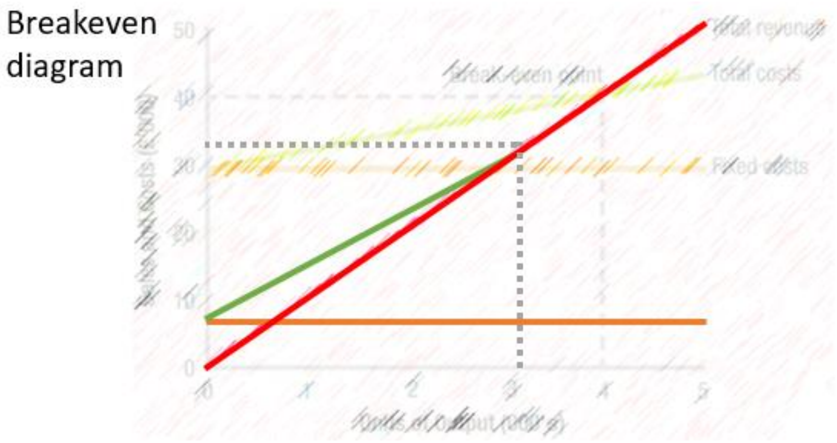
- In general, a company with lower fixed costs will have a lower break-even point of sale.

Breakeven diagram





Exercises
1. How much are the fixed costs? 2. How much are the variable costs at 4.000 units? 3. How much are the total costs for 4.000 units? 4. How much is the profit at 4.000 units? 5. How much is the profit at 5.000 units? 6. How to compare two different types of production, e.g. two different ways of timber drying with different costs and investments? 7. How to compare two different types of production? How to compare two different ways of timber drying with different costs and investments? And which one is more profitable?



CAPEX Capital expenditure (fixed costs)

- Property
- Kiln, boiler, plant machinery
- Office building
- Other buildings, workshop, boiler house
- Roads, storage area, warehouse
- Forklift, tractor, telehandler, car
- Office equipment
- Tools, maintenance, testing equipment
- Interest, repayment, depreciation?
- What is depreciation?
- Depreciation represents how much of an asset's value has been used.
- There are many types of depreciation, including straight line and forms of accelerated depreciation.
- In the following we only use the straight line method for matters of “technical depreciation”.
- When using the straight line method, the annual depreciation charge is consistent over the years.

OPEX Operational expenditure (variable costs)

- Electricity (kiln, plant)
- Heat from biomass
- Office costs
- Plant maintenance

- Vehicle fuel, maintenance
- Staff, management, technicians, drivers, hands
- Raw material? Buying and selling prices?
- Tax?
- Insurances?

Total costs and specific costs of drying

- According to the Excel chart the total costs of drying eucalyptus and drying pine are not that different!

Total costs of drying of eucalyptus timber per year	€/a	114.635,29	65.567,65	40.783,82
Specific costs per cbm of dried eucalyptus timber	€/cbm	127,37	145,71	181,26

Total costs of drying of pine timber per year	€/a	134.394,12	75.447,06	45.723,53
Specific costs per cbm of dried pine timber	€/cbm	38,40	43,11	52,26

2.6.7 Rwandan market analysis

- The profitability of a timber drying business very much depends on market requirements and market prices of green timber, air dried (AD) timber and kiln dried timber (KD).
- A market is a place where buyers and sellers can meet to facilitate the exchange or transaction of goods and services.
- Markets establish the prices of goods and services that are determined by supply and demand.
- The profitability of a timber drying business very much depends on market requirements and market prices of green timber, air dried (AD) timber and kiln dried timber (KD).
- A market is a place where buyers and sellers can meet to facilitate the exchange or transaction of goods and services.
- Markets establish the prices of goods and services that are determined by supply and demand.

2.6.8 Drying as a service

- What to consider if drying someone else's timber:
- Will they let you air dry it first?
- What is the initial MC? What is the required final MC?
- Does the batch has uniform dimensions and species?
- Do they want you to stack and to un-stack it? Or will they take your stickers away?
- Do they want you to store it for a few days?
- Who has insurances in case of flooding, storm or fire?

- Who will be responsible for quality loss and defects?
- Do you have a contract to indicate responsibilities?
- When a cooperative is running a kiln and dries timber for its members, it is also a sort of “drying as a service” and the same questions have to be considered!
- Why are the “stand alone kiln drying operation” and also the “integrated sawmilling and kiln drying operations” both rated as “no high-risk businesses” in the mentioned feasibility study?
- What are the obstacles in Rwanda?
- How do you do the costing and the pricing for “drying as a service”?

LEARNING UNIT 3: CHECK TIMBER QUALITY

3.1 Identify dry timber defects

3.1.1. Key definitions

- A defect might be any irregularity or imperfection in a tree, log, bolt, lumber, or other wood product that reduces the volume of useable wood or lowers its durability, strength, or utility value.
- Defects may result from knots and other growth conditions, insect or fungus attack, from poor sawmilling, drying, machining, or other processes.

3.1.2 Biological defects – Mold and stain fungi

- Mold and stain fungi do not seriously affect most mechanical properties of wood because such fungi feed on substances within the cell cavity or attached to the cell wall rather than on the structural wall itself.
- However, the duration of infection and the species of fungi involved do determine the extent of degradation.
- Although low levels of biological stain cause little loss in strength, heavy staining may reduce specific gravity, surface hardness, bending and crushing strength and toughness or shock resistance.
- Unlike mold and stain fungi, wood-destroying (decay) fungi seriously reduce strength by metabolizing the cellulose fraction of wood that gives wood its strength.
- Early stages of decay are virtually impossible to detect. For example, brown-rot fungi may reduce mechanical properties in excess of 10 % before a measurable weight loss is observed and before decay is visible. When weight loss reaches 5 to 10 %, mechanical properties are reduced from 20 to 80 %.
- Decay has the greatest effect on toughness, impact bending, and work to maximum load in bending, the least effect on shear and hardness, and an intermediate effect on other properties.
- Decay can be prevented from starting or progressing if wood is kept dry (MC < 20 %).

Most wood that has been wet for a considerable length of time probably will contain bacteria, what has little effect on wood properties, except over long periods:

- Bacterial infection can result in excessive absorption of moisture, adhesive, paint, or preservative during treatment or use. This effect has been a problem in the sapwood of millwork cut from pine logs that have been stored in ponds.
- Bacteria may also change the colour of the infested wood (see 3.1.4.4).

- There also is evidence that bacteria developing in pine veneer bolts held under water or sprayed with water may cause noticeable changes in the physical character of the veneer, including some strength loss.
- Damage is done by beetles, termites, ants, bees, marine borer and shipworms.
- Insect damage may occur in standing trees, logs, and undried (unseasoned) or dried (seasoned) lumber. Although damage is difficult to control in the standing tree, insect damage can be eliminated to a great extent by proper control methods.
- Insect holes are generally classified as pinholes, grub holes, and powder post holes.
- No method is known for estimating the reduction in strength from the appearance of insect-damaged wood. When strength is an important consideration, the safe procedure is to eliminate pieces containing insect holes.
- All efforts should have been made to keep the timber yard, saw milling, drying and further processing operations free of insects!

3.1.3 Natural defects which occurred before drying

- Many natural features of wood affect its utility when it is processed into lumber and special products. These includes knots, ring shake, bark, mineral streaks, pitch pockets, compression and tension wood, juvenile wood, and spiral or interlocked grain.
- All of them form in the tree and directly influence the grade, the appearance and value of each individual board.
- Because they are characteristic features of the individual species, of the individual tree and of the region where it grows, one should not speak of a "defect".
- Ordinary processing of lumber may remove some of these natural features through trimming and thus improve the quality and value of the remaining piece.

3.1.4 Defects caused by improper kiln drying

Most defects or problems that develop in wood products during and after drying can be classified under one of the following categories:

- Rupture of wood tissue,
- Warp,
- Uneven moisture content, and
- Discoloration.
- Defects in any one of these categories are caused by an interaction of wood properties with processing factors.
- Wood shrinkage is mainly responsible for wood ruptures and distortion of shape.

- Cell structure and chemical extractives in wood contribute to defects associated with uneven moisture content, undesirable color, and undesirable surface texture.
- Drying temperature is the most important processing factor because it can be responsible for defects in each category.

Temperatures ranging from 140 to 160 °F (60 to 70 °C) have little effect on mechanical properties

Rupture of wood tissue

- Many defects that occur during drying result from the shrinkage of wood as it dries.

In particular, the defects result from uneven shrinkage in the different directions of a board (radial, tangential, or longitudinal) or between different parts of a board, such as the shell and core

Surface checks

- Surface checks usually occur in the wood rays on the flatsawn faces of boards.
- They occur because drying stresses exceed the tensile strength of the wood perpendicular to the grain, and they are caused by tension stresses that develop in the outer part, or shell, of boards as they dry.
- They develop because the lumber surfaces get too dry too quickly as a result of relative humidity that is too low (e.g., during the early stages of kiln drying).

End checks and splits

- End checks (like surface checks) occur in the wood rays, but on end-grain surfaces.
- They also occur in the early stages of drying, but might be already present in the log as growth stress.
- They can be minimized by using high relative humidity (in the kiln) or by end coating.
- They occur because moisture moves faster in the longitudinal direction and therefore, the ends of boards dry faster than the middle and stresses develop at the ends

Collapse

- Collapse is a distortion, flattening, or crushing of wood cells. In severe cases, collapse shows up as grooves or corrugations (wash boarding effect).
- Slight amounts of collapse are usually difficult to detect at the board level and are not a particular problem.

- Collapse may be caused by (1) compressive drying stresses in the interior parts of boards that exceed the compressive strength or (2) by liquid tension in cell cavities that are completely filled with water.

Honeycomb

- Honeycomb is an internal crack caused by a tensile failure across the grain and occurs in the wood rays.
- This defect develops because of the internal tension stresses that develop in the core of boards during drying. It occurs when the core is still at a relatively high moisture content and when drying temperatures are too high for too long during this critical period.
- In many cases the defect is not apparent on the sur-face, and it is not found until the lumber is machined.

Ring failure

- Ring failure occurs parallel to annual rings either within a growth ring or at the interface between two rings.
- It is similar in appearance and often related to shake, which is the same kind of failure that takes place in the standing tree or when the tree is felled.
- It can occur as a failure in the end grain in the initial stages of drying.
- It can be kept to a minimum by end coating and by using high initial relative humidity and low temperature schedules.

Boxed-heart splits

- A boxed-heart split starts in the initial stages of drying and become increasingly worse as the wood dries.
- The difference between tangential and radial shrinkage of the wood surrounding the pith causes such severe stresses in the faces of the piece that the wood is split.
- It is virtually impossible to prevent this defect.

Checked knots

- Checked knots are often considered defects. The checks appear on the end grain of knots in the wood rays.
- They are the result of differences in shrinkage parallel to and across the annual rings within knots.
- Checked knots occur in the initial stages of drying and are aggravated by using too low a relative humidity.
- These defects can be controlled by using higher relative humidity and by drying to a higher final moisture content, but it is almost impossible to prevent them.

Loose knots

- Encased knots invariably loosen during drying because they are not grown into the surrounding wood but are held in place by bark and pitch only.
- These knots shrink considerably in both directions (across the width and along the length), whereas the board shrinks considerably in width but very little in length.
- Consequently, the dried knot is smaller than the knot-hole and frequently falls out during handling or machining.

Casehardening

Drying stress, also called “casehardening” or “tension set”, is a normal occurrence in drying (and therefore not exactly a defect). It can easily be relieved at the end of drying:

- While still in the kiln, the stock is subjected to a fairly high temperature and 4 % EMC above the desired average moisture content for the stock.
- Spraying is usually needed to increase RH for a specific length of time according to the drying schedule.
- The cause of drying stresses is the differential shrinkage between the outer part of a board (the shell) and the interior part (the core):
- Early in drying, the fibres in the shell dry first and begin to shrink. However, the core has not yet begun to dry and shrink; consequently, the core prevents the shell from shrinking fully.
- Thus, the shell goes into tension and the core into compression (a).

As drying progresses, the core begins to dry and attempts to shrink:

- However, the shell is set in a permanently expanded condition and prevents normal shrinkage of the core.
- This causes the stresses to reverse; the core goes into tension and the shell into compression (b).
- These internal tension stresses may be severe enough to cause internal cracks (honeycomb).

Two basic methods are used for preparing stress sections to identify casehardening. Both methods operate on the principle that transverse stress (= perpendicular to axial stress) will become unbalanced when lumber is sawn:

- The first technique indicates whether stress is present and how severe it is.
- The second technique provides a visual guide to the extent of moderate to severe stress.

Warp

- Warp in lumber is any deviation of the face or edge of a board from flatness or any edge that is not at right angles to the neighboring face or edge (squares).
- It can cause significant volume and grade loss.
- All warp can be traced to two causes; differences between radial, tangential, and longitudinal shrinkage in the piece as it dries, or growth stresses.

Various types of warp that can possibly develop In boards during drying:

- Cup,
- Bow,
- Crook,
- Twist, and
- Diamonding.

Uneven moisture content

- Wood is dried to an average moisture content that is compatible with subsequent processing operations and the use of the final product.
- Uneven moisture content refers to a condition where individual boards in a kiln charge have a level of moisture content that deviates greatly from the target moisture content.

Board rejects (because of uneven MC)

Boards are rejected for immediate processing and end For two reasons:

- The average board moisture content is either above or below an acceptable range for the intended moisture content or
- The average moisture content of the entire board is within the acceptable range, but the core of the board has a water (wet) pocket that cannot be tolerated in the next processing step.

Water pockets

Some boards will have acceptable overall average moisture content and yet have internal water pockets or streaks with moisture contents of 10 percent or higher than the average. Surfacing of boards containing water pockets can result in surface depressions when the core eventually dries.

- Resewing boards with water pockets results in bowing and twisting of the new pieces.

Control measures (regarding uneven MC)

Causes	Control measures

Discoloration

The use of dried wood products can be impaired by discolorations, particularly when the end use requires a clear, natural finish. Unwanted discolorations can develop in the tree, during storage of logs and green lumber, or during drying.

Discolorations may also develop when light, water, or chemicals react with exposed surfaces of dried wood. However, this section is mainly concerned with discolorations that develop in clear, sound wood before or during drying.

To prevent discolorations, the dry kiln operator must know the wood species and de-termine the wood type (sapwood, heartwood, or wet wood). The third step is to determine if the causal factors are primarily chemical or microbial.

Sapwood discolorations

When the tree is cut, sapwood contains living parenchyma cells, which are not present in fully formed heartwood.

Sapwood parenchyma cells may still be alive when the logs are sawed into lumber.

Sapwood also contains starches and sugars that provide food for mold fungi and bacteria.

As these cells die, enzymes and chemical by products are produced that may darken the wood.

This darkening is intensified by oxidative heating of, the moist wood or by attack by fungal moulds or aerobic bacteria.

Chemical discolorations are the result of oxidative and enzymatic reactions with chemical constituents in the sapwood. They range in color from pinkish, bluish, and yellowish through gray and reddish-brown to dark brown shades, but are mostly found in hardwoods.

Aerobic bacteria and its by-products will discolor the wood during kiln drying. Sticker stains and sticker marks are caused by chemical, microbial, or a combination of these.

Fungal stains, often referred to as blue stain, are caused by fungi that grow in the sapwood and use parts of it (such as sugars and starches) for food.

Sapwood discolorations – Blue stain

Blue stain fungi do not cause decay of the sapwood, and they cannot grow in heartwood that does not have the necessary food substances.

However, poor drying conditions that favor the growth of blue-stain fungi can lead to infections by decay-producing fungi.

With the exception of toughness, blue stain has little effect on the strength of the wood.

To prevent blue stain, it is necessary to produce unfavorable conditions for the fungi.

Blue-stain fungi are disseminated by spores, which are produced in great abundance and are disseminated by wind and insects, or by direct growth/contact from infected to uninfected wood.

Blue-stain fungi will survive but cannot grow at a MC of 20 % or lower or a temperature of 110 °F (45 °C). Temperatures above 150 °F (65 °C) are lethal to the fungi. This means the dry kiln operator may be able to employ drying schedules for control.

In the summer months and in the tropics, the operator will need to chemically treat the wood with fungicides in addition to using proper kiln schedules.

Heartwood discolorations

Discoloration during the drying of heartwood will usually be chemical in nature and not as frequently encountered as when drying sapwood.

Fungal discolorations will never develop under satisfactory drying conditions if the green heartwood is sound. Bacteria are not a problem when drying heartwood, but they do contribute to drying discolorations in wet wood, which is considered an abnormal type of heartwood.

Metallic and alkaline stains

Metallic discolorations are mostly iron tannate stains and are likely to develop in oak, chestnut, and walnut, and, to a lesser degree, in other species during kiln drying from steam condensates and water dripping from steel pipes, beams, and other kiln components.

Dark alkaline stains are caused by the chemical reaction of wood extractives with potassium and calcium hydroxides that leach out from concrete and mortar structures in contact with the wood.

Removal of discoloration from dried wood

Although preventative measures are advocated here, it may sometimes be economically necessary to remove discolorations that cannot be surfaced off on the planer.

Some stains may be removed with a bleaching agent, but some trial and error method is often required to find the most effective agent for a particular stain.

If the stain is not too deep, it can often be removed or reduced in intensity with hydrogen peroxide.

A concentrated aqueous solution of oxalic acid will bleach out chemical sapwood stains but not sapwood stains caused by mold fungi. A laundry bleach of 5 percent sodium hypochlorite solution can sometimes be used effectively.

3.1.5 Timber grades

➢ FAS grading system

- Grading is done by inspecting the worth face of the sawn timber in a majority of cases.
- Nevertheless, in some rare cases, for some particular or high value species, it is possible to meet rules allowing grading on the best side.
- Planks must be looked on both sides before choosing the grading side.
- In Europe and the U.S., FAS grade is the most requested grading system, especially for (decorative) hardwoods, but it can be applied to non-structural softwoods, too:
- FAS means ‘First and Second’, where 1st grade should represent min. 60 % of the parcel, and the second grade should not exceed a max. of 40 % of the parcel volume.
- FAS One Face (F1F) grade calls for the piece to meet the FAS grade requirements for the so-called better face of the board, while the poor face can meet the requirements of the lower number 1 common grade.
- This grade is often mixed with FAS when sold in an agreed-upon percentage such as 80 % FAS / 20 % F1F.

Different rules are managing FAS grading and Richard Fays proposes a summarized grading considering 3 kinds of grades:

- High grade free of any defect or presenting small defects
- Standard grade presenting allowed defects
- Low grade to be rejected, presenting unacceptable defects.
- This system is only for visual or appearance grading,
- Not for stress grading or load bearing timber!
- High grade (best, including 1^{st} and 1^{bis}) presenting:
- No defect (1^{st}) or small defects (1^{bis}) as small splits in ends appearing one side only mall sound knots (less than 10 mm diameter), appearing only one side small pin holes appearing one side only.

Standard grade (fair) presenting allowed defects as: splits in ends, less than 5 % of the length, appearing or not on both sides sound knots less than 50 mm diameter, appearing or not on both sides small bark pocket in size less than 3 % of length and less than 3 % of width on 1 side pin holes appearing on both sides or numerous (no important concentration) pin holes small surface of discoloration (blue stain) small touch of sap wood, appearing on 1 side only, less than 10 % (1/10) of length, less than 20 % (1/5) of width and less than 30 % (1/3) of thickness.

Low grade (reject) includes:

- Decay and/or rot heart
- Bark pocket exceeding 3% of length and width in size and/or appearing on both sides
- Dead or unsound knots
- Sound knots exceeding 50 mm diameter
- Borer holes
- Important discoloration or blue stain
- End splits exceeding 5% of length and/or appearing on both side … (complete list see: Richard Fays, Rwandan grading training course, GOPA/GIZ, 2021)

Grading of wooden furniture

- DRS 413 “Furniture – Quality and grading of wooden furniture” establishes guidelines for classification and grading of furniture components for general application in furniture and similar products.

- This standard spells out the requirements for machined wood products intended for general application in furniture including furniture for load bearing, furniture for non-load bearing and furniture for decorative art.

3.2 Record dry timber measurements

3.2.1 Timber dimensions (length, width, thickness)

The thickness at the moment of timber inspection, must correspond to MC of 20 %.

- If the timber is already dried, or has a moisture below 20 %, the thickness could be a few lower than the contractual thickness, considering that the timber has already dried and will not retract more or too much.
- Fresh timber is sawn at sizes superior at the maximal allowed size, knowing that the timber will dry and its sizes will reduce.
- The maximal sizes are superior to the real size to cover sizes reduction during drying.
- And the real size must be superior to the nominal or contractual size, to ensure the client to reach his final size after drying and surfacing.

This drawing shows the different sizes:

- Sawing size (in black)
- Maximal size allowed (in red)
- Real size (in blue grey)
- Nominal size (or contractual size in green)
- Board's volume is calculated as follows: V = L x w x Th
- **L** is the Length in meter, rounded at covered decimeter (3.40 up to 3.49 m = 3.40 m)
- **W** is the width in meter, rounded at covered centimeter (33.0 up to 33.9 = 33 cm = 0.33 m)
- **Th** is the thickness in meter, rounded at covered millimeter (27.0 up to 27.9 mm = 27 mm = 0.027 m)

LEARNING UNIT 4: STORE TIMBER

4.1. Identify green and dried timbers storage facilities

4.1.1: Types of wood species

- **Green and Partially Dried Lumber**

Green or partially dried lumber usually undergoes controlled drying when in storage, and is usually stickered and given some protection from weather.

Green lumber bulk-piled for extended storage during warm weather is in danger from decay, stain, and insect attack. For this reason, green lumber should be stickered for drying as soon as possible after sawn. When such lumber must remain bulk-piled in warm weather, such as when shipped in the green state, it is often protected by chemical treatment. Green lumber will lose moisture when it is stored and should be stickered.

- **Dry, High-Grade Lumber**

At times the maximum moisture content acceptable for construction lumber is set by industry practice, and at other times by standards and codes.

Certain industry grading rules, for example, require that softwood dimension lumber used in the framing of houses be below 19 percent moisture content. Lumber for use in the heated interiors of buildings should properly be still drier; its moisture content should not exceed 8 percent.

Therefore, those who handle dried high-grade lumber must be careful that it not take on excessive moisture in storage or transport.

For example, finished lumber at a construction site should not be allowed to undergo soaking from rain because this would jeopardize its structural performance.

The problem is especially acute with kiln-dried lumber to be used in an interior location. If such lumber becomes wet enough to require redrying, additional labor and expense are required.

Also, the lumber will again undergo some degrade from the drying process and refinishing may be required. Dry, high-grade lumber is best protected from moisture regain when stored as solid packages under roof.

Closed storage sheds offer the best protection from moisture regain during long-term storage

➢ Dry, High-Grade Lumber

At times the maximum Pallet packages of lumber stored in an open shed.

Some packages have been unitized with iron bands (centre). Other clad in plastic film for additional protection. Kiln dried, finished softwood lumber stored in a large closed shed. The strapped packages are transported by an overhead gantry crane.

➢ Unprotected Lumber Outdoors

High-quality lumber will endure for a short time storage conditions which, if sustained, would cause grade and footage losses. How tolerant any given lot of lumber may be to lack of protection, such as when transported on open trucks, depends upon the time exposed, the weather, and qualities of the lumber itself.

Generally, thicker pieces of wood, such as dimension lumber, will regain moisture more slowly than thinner pieces, such as nominal 1-inch boards. Hardwoods are more resistant to moisture regain than softwoods, dense woods more resistant than less dense, and heartwood more resistant than sapwood.

Storage without roofing/short-term: three to maximum five months' tree species like Douglas fir, Spruce, Larch, pine, Control of atmospheric conditions during lumber storage, principally relative humidity, can create a moisture balance in the lumber suited to its end use. Thus the lumber's commercial quality can actually be improved by storage.

Dry lumber is usually bulk-piled when stored so that the over dried boards can absorb moisture from adjacent under dried boards.

Moisture content differences between boards of the lot are thereby lessened. The moisture gradient within individual boards also tends to flatten out during storage. That is, the difference in moisture content between the shell and core of each board is lessened.

Storing dry, casehardened lumber in an atmospherically controlled shed or warehouse will usually result in only slight stress relief. However, if such lumber is stickered in an open shed the regain of moisture by the surfaces will reduce casehardening stresses

➢ Moisture changes in stored lumber

If moisture content in stored lumber becomes greater than about 25 percent, lumber becomes susceptible to decay, stain, or insect attack. Furthermore, uneven wetting or drying of lumber will cause warp. Grade loss due to moisture change can be prevented, but methods differ for green, air-dry, and kiln-dry lumber.

Green lumber loses moisture to the air during storage, and if dried unevenly will warp. Stickering green lumber prevents warp by allowing air to circulate through the pile. Moisture can then evaporate evenly from all faces of the boards, and uneven shrinkage stresses are prevented.

Kiln-dry lumber tends to take on moisture from the air; storage procedures should thus minimize or prevent moisture regain. If kiln-dry lumber regains much moisture, the expense and effort of the kiln-drying process may have been wasted.

Techniques for controlling moisture movement in lumber fall into three categories: (1) determining the moisture content of stored lumber; (2) predicting and, in some instances, controlling moisture loss or regain; and (3) calculating the dimensional changes in lumber caused by changes in moisture content

➢ Dry Storage

- You are going to plan a dry storage for timber. Everything to be considered is listed in this recommendation.
- Exposed to wind, constantly ventilated, dry, warm, and not shady. The logs may only be exposed to extreme solar radiation if storage duration is kept short.

- Roofing: Sufficient ventilation underneath the roof is needed. The roofing should extend over on the sides. Roofing is very expensive; the need has to be examined carefully. Drying and ventilation of the pile can be hindered near the roof if the roofing is mounted improperly.
- Sufficient ground clearance by using large logs as under layer. Roofing does not have to happen at once, but the timber should be protected from precipitation as quickly as possible;

4.1.2 Effect of climate on lumber storage

- Air temperature, relative humidity, and rainfall of the 'storage region affect procedures to protect lumber stored outdoors.
- **Relative Humidity**
    - ✓ Relative humidity has a much greater effect on wood's equilibrium moisture content (EMC) than does temperature. That is, the more humid a region, the more rapidly dry lumber will take on moisture when yarded there.
    - ✓ Seasonal estimates of the average wood EMC for a region can be helpful when trying to control moisture change in lumber stored outdoors. Storage requirements may differ from month to month in regions where average relative humidity varies considerably with seasons.
- **Temperature**
    - ✓ Air temperature affects stored lumber because warming speeds up moisture diffusion and thus increases lumber's rate of moisture change.

➢ Temperature

Thus, if moisture differences between boards in the lot need to be reduced, storage of lumber in warm air temperatures is advantageous. Warm temperatures also increase the hazard of fungal infection in stored lumber.

All lumber is practically immune to fungal infection below 30° F (–10 C). When green lumber is solid piled, mold, stain, and decay fungi will grow at temperatures from 400 to 1000 F (about 50 to 38° C) with rate of attack increasing rapidly at higher temperatures in this range.

Dipping or spraying freshly sawed lumber with an approved fungicide appreciably reduces the likelihood of fungal growth.

➢ Rainfall

When lumber is stored outdoors with good protection, rainfall does not greatly affect its moisture content. Bulk-piled green lumber is often temporarily stored outdoors unprotected before stacking for air drying or kiln drying

Some wetting of green lumber is not considered hazardous. If, however, green lumber has been treated with a fungicide for extended green storage or shipment, protection from rain is needed. Rain would leach the chemicals from the exposed boards. Bulk-piled dry lumber should be protected from rain, preferably in storage sheds. Redrying bulk-piled lumber that has been wetted by rain is difficult.

➢ Softwoods Green lumber.

Treat green lumber with a fungicide if bulk storage is extended, particularly during the warmer months. Species like the white pines must be stacked for drying soon after sawing to avoid brown stain.

- **Kiln-dried lumber.**

  Store dry lumber, both rough and finished, under cover. Keep shed access doors closed during off-work periods. Inspect wrapped packages of finished lumber stored outdoors for wrapper ‘breaks and tears. Re-dry wetted lumber.

- **Hardwoods Green lumber.**

  Stack for air drying or kiln drying soon after sawing. Treatment with a fungicide may be necessary during warmer months to prevent sap stain

➢ Hardwoods Green lumber.

Air-dried lumber.

Store under cover to prevent moisture regain. Covers on outside bulk piled stock should effectively prevent rainwater entry. Keep bulked piles off of the ground to allow ventilation.

Air-dried lumber can be stored in closed sheds, either bulked or on sticks. Keep shed doors closed when possible. Kiln-dried lumber. Store as bulked lumber in closed, heated sheds.

Storage Facilities

Green lumber often arrives at a woodworking factory as solid packages which are then stickered for drying.

Slower drying hardwoods like oak are built into unit packages for drying in a conventional air-drying yard or in specially built open sheds.

However, some woodworking plants air dry hardwoods such as oak on kiln trucks prior to kiln drying.

The faster drying hardwoods are usually stickered for kiln drying while green, although the thicker sizes may require air drying first. Green softwoods are stickered for immediate kiln drying.

Air-drying yards at woodworking factories should be located at sites favoring good drying.

Such yards should be laid out to facilitate lumber handling. The alleys or roadways are often paved and the pile foundations permanent, particular y in line-type yards. Pile covers should be used.

Yarding is usually done with forklift trucks because most woodworking factories have converted their air-drying yards from hand-built piles to unit-package handling. Partially air-dried lumber, either softwood or hardwood, is usually stickered for kiln drying.

Stickered unit packages are sometimes stored outdoors without protective cover before loading into a package-loaded dry kiln, or are placed on kiln trucks for drying in a track-type dry kiln.

Kiln-truckloads of green, practically air-dried, or well air-dried lumber are sometimes stored in a “green” end storage shed of a dry-kiln installation before loading into the dry kiln. Such storage under roof protects high value lumber.

If kiln-dried lumber must be stored outdoors, it should be bulk piled well off the ground on supporting foundations.

Sheet plastic covers on these piles will cut down moisture regain. If the storage period is extended, redrying may be necessary, requiring that the lumber be stickered. Unit packages of softwood lumber, kiln dried and wrapped, are often stored outdoors at millwork factories.

The storage period is usually brief. In extended outdoor storage, the wrappers on kiln-dried packages of lumber should be periodically inspected and repaired. Extended exposure of unit packages with damaged wrappers can increase losses due to stain and decay.

4.1.3. Storage Climatic Conditions

- **When is timber/lumber said to be in storage?**

Between cutting and use, lumber undergoes a complex series of stages in processing and transport.

During this time, lumber is frequently stored. After drying and planning, softwood lumber maybe stored before shipping, and then stored again in trucks, railroad cars, or a ship's hold as it moves toward a destination.

Hardwood lumber is usually dried at the producing sawmill and moves as rough lumber to the using factories.

Finally, lumber may be stored at wholesale and retail distribution yards, at woodworking plants, and at the construction site. The moisture content of lumber must be controlled in storage.
Moisture changes in lumber may at times be the direct cause of grade loss. The best lumber will be unsuitable for many uses if its moisture content goes too high. Also, moisture changes in lumber may be an indirect cause of deterioration

- **Wet storage**

Wet storage is the most commonly used preservation method for timber and pulpwood at Scandinavian saw and pulp mills.

It is of current interest during the warm months of the year, when the risk of drying-out of wood is at a maximum. Wet storage of wood is applied to protect against fungal and insect attacks and to prevent checking.

The two most common methods worldwide are sprinkling and ponding of land-stored timber. It can be assumed that the success of wet storage should only be dependent on the relationship between evaporation from wood and the amount of water applied on the round wood piles.

If the round wood during the summer is stored unprotected, or if the sprinkling intensity is too low, the round wood will be exposed to damage connected with drying-out. The main risks then are blue stain, beetles, development of end checks and debarking problems.

On the other hand, if too heavy sprinkling intensities are used or if the wet storage period is too long, other negative effects on the quality of round wood may occur.

These effects are bacterial damage in wood, bark stain and negative influences on the environment.

The year can be divided into three periods of storage

1. Winter. The coldest season, when no insects are attacking the timber. The fungi are not active and the timber is dry stored during this period.
2. Spring, early summer. This period has the highest activity of fungi, and also the largest amounts of insects. This is the period when timber is wet stored, usually by sprinkling.
3. Indian summer, autumn. Characteristic for this period is high temperature combined with high atmospheric humidity. That favour different kinds of fungi. The timber is still wet stored, often until the end of October, depending on the prevailing weather.

By improper wet storage, the round wood quality and the added value of the raw material can be wasted.

On the other hand, it is important to remember that the quality of the round wood can only be retained at a level that prevails when the round wood enters the mill and wet storage.

Once the freshness and quality are lost, it is impossible to repair by using wet storage or other methods.

➢ Sprinkling (wet storage)

Where log decks are a preferred manner of storage, sprinkling the decks with water provides an effective method for reducing checking, sapwood stains, and decay when the temperature is above freezing.

The traditional way of doing this was developed in the beginning of 1930's in order to protect timber lying above the water surface in storage ponds.

According to the last nationwide Sawmill Inventory, for year 2000, 84% of Swedish sawmills producing over 100 000m3 wood products/year protect their timber by water sprinkling.

It can be roughly assumed that the remaining 16% do not take any wood protective measures during storage.

The mean temperature inside the stacks is reduced by 2-4°C as a result of sprinkling, which leads to a longer developmental stage from the egg to the mature insect.

Saturating with water must greatly limit the availability of oxygen for the insects in the bark. This may explain the high mortality and the stunted development. However, the reduction of oxygen from continuous soaking of the wood is the main reason to sapwood staining and decay fungi.

➢ Pond storage (water storage)

A log submerged in water is protected completely from drying defects and from insect and fungi attacks.

Pond storage includes logs that are stored in lakes, rivers, and salt-water estuaries as well as millponds. Pond storage was once very common, but has, as a protective measure, more or less ceased due to its negative impact on the water as well as deterioration of wood quality.

Pond-stored logs are usually banded together to increase the log-holding capacity of the pond and to prevent wet wood-logs from sinking to the bottom. Some parts of most logs stored in ponds are above water and may develop drying defects such as end checking, and they are exposed to attacks by insects and fungi if stored too long during warm weather.

Logs rafted and stored in ocean water are also subject to attack by marine borers and salt water microorganisms.

Storage in lakes cause a change of the bottom sediments, an addition of organic substances to the water and, sometimes, to increased acidity. The breakdown of organic substances leads to oxygen demand at the same time as the supply of oxygen and sunlight irradiation into the lake is reduced by the stored timber.

4.2. Types of timber yards

4.2.1 Storing Lumber in Sheds

Storage sheds offer lumber the best protection from weathering, and also eliminate the expense of making, storing, handling, and maintaining pile covers.

Losses in grade and footage through outdoor air drying have stimulated an increased interest in using open sheds for drying. Open sheds provide permanent roofs, and can also be used for storing air-dry lumber.

Further modification-by closing up open sheds, installing fans to create air circulation around the stored lumber, and adding heat-can appreciably lower the moisture content of stored lumber.

- **Open Sheds**

An open shed is a roofed lumber storage yard. All lumber items except those kiln dried to moisture contents of less than 12 to 14 percent can be stored in open sheds.

The atmospheric conditions within an open shed are substantially those found outdoors. If the outdoor air can circulate through and around stickered packages, the lumber will dry to as low a value as it does in an exposed air-drying pile.

The drying period in an open shed is usually shorter and the lumber brighter than if stored outdoors because wetting and rewetting are prevented. Bulk-piled, kiln-dry lumber will regain moisture with extended storage in an open shed, although more slowly than if stored unprotected. Increase will be greatest in the outer tiers of a solid pile.

For example, surfaced boards of 1-by 8-inch kiln-dry Douglas-fir averaged 6.9 percent moisture content when put in storage at a western sawmill.

Moisture content of the boards increased by 3.4 percent when stored for 1 year as a carrier package in an open shed. The two outer tiers of boards in the five-tier package increased 3.8 percent in moisture content, the center tier 2.7 percent.

A shed maybe opens on all sides or on one side only. Where unit packages are handled by forklift truck, access to the shed is provided by one or two open sides. The rows of piled packages may run across the shed in bays between the roof supports.

Where lumber is handled manually in and out of bins, as at some retail lumberyards, a driveway between the open sheds provides access.

The roofs of these open sheds usually extend far enough over the driveway so that trucks can be loaded and unloaded in rainy weather. Open sheds at the larger lumber-producing sawmills are usually paved for forklift trucks and other carrier vehicles.

Cranes operating within open storage sheds for dry, rough lumber are generally of the monorail or bridge type, and pile foundations are built up on the graded ground.

At small sawmills and retail lumberyards, open sheds are not always paved, although the roadways may be graded or graveled.

Open storage sheds at wholesale lumberyards and woodworking factories usually have paved floors and driveways.

➢ Closed, Unheated Sheds

Closed, unheated sheds are generally used for storing kiln-dry lumber. The object during storage is to maintain the percent moisture content attained by the drying process.

Thus, lumber should be solid-piled in closed, unheated sheds, with only enough tie strips to stabilize the package or to designate species, quantities, grades, or items within it.

Kiln-dry lumber stored in an unheated, closed shed will absorb some moisture, but less than if it were stored outdoors.

For example, l-inch southern pine boards in a solid pile went from 7½ to 10¼ percent average moisture content during 1 year of storage in a closed shed. Similar lumber which was solid-piled outdoors for the same period reached a moisture content of 131, 4 percent.

Storage in an unheated, closed shed will also decrease the moisture gradient in stored lumber—that is, the difference between the moistest and least moist boards in the package.

For example, solid-piled packages of rough 1- by 6-inch kiln-dry clear Douglas-fir boards were stored in a large, unheated storage shed for 1 year. Curves showing the range of moisture content before and after the storage period are seen in figure 25. The range in the lumber's moisture content before storage was about 20 percent; it was 13 percent after storage. Although the range was reduced, the reduction was generally at the expense of the dry boards in the unit packages. Ninety-five percent of the boards in the packages underwent an increase in moisture content.

The roof and walls of a closed shed absorb solar radiation and in turn heat the air inside. The warmed air, however, tends to remain in the upper parts of the shed.

To be effective in lowering the equilibrium moisture content conditions around the stored lumber, the warm air must be moved downward and circulated by fans. Forced circulation, even without additional heating, is beneficial.

Forced circulation, together with an additional source of heat, will convert a closed, unheated shed to a closed, heated shed. Closed, unheated sheds for lumber storage should be floored or paved if the handling equipment operates on the floor surface.

If the closed shed is not paved, it should be located on a high, well-drained site. Sometimes the closed shed will have an elevated wood-decked tramway and wood floor if it is built over low ground. In that case, good ventilation of the space under the floor is essential.

Large, closed, unheated sheds with overhead bridge cranes are not floored except where surface equipment operates to load railroad cars and trucks.

The pile foundations in unpaved sheds should be so designed and constructed that air can circulate freely under the bottom packages. At some sawmills, lumberyards, and woodworking factories, lumber is moved in and out of racks or bins in the unheated, closed sheds.

Aisles or driveways are provided for transporting the lumber to and from the bins, so’ that it can be solid piled in the bins without difficulty. Some items at sawmills and wholesale and retail yards are placed on end in stalls. Paving the floor of these stalls assures dry ends.

Closed, unheated sheds beside railroad sidings often have an elevated floor to facilitate lumber handling in and out of boxcars. The crawl space under the elevated floor needs to be well ventilated.

➢ Closed, Heated Sheds

If the air in a shed is heated, EMC conditions are lowered. Moisture regain by stored dry lumber can thereby be prevented. Closed lumber sheds can be heated to lower the wood EMC by steam-heating coils, radiators, or unit heaters. Gas-fired unit heaters are sometimes installed. lt is essential that some air circulation be created by strategically located fans. The heat supply can be controlled manually or automatically.

Manual control requires frequent observations of outdoor and indoor wet- and dry-bulb temperatures so that the relative humidity in the shed can be estimated and valve settings adjusted accordingly.

Temperature control in closed, heated sheds is often by a simple thermostat which regulates either the heater or the heater fan. With changing outdoor temperature and relative humidity, the thermostat in the storage area needs to be frequently reset to maintain the desired wood EMC.

Differential thermostats require less adjustment than simple thermostats in controlling shed heating. They automatically maintain shed temperature a fixed number of degrees higher than the outdoors temperature.

Differential thermostats will maintain an approximate EMC level without periodic readjustments.

They are inexpensive, and are available from a number of national suppliers. Humidistats will initiate heating when the relative humidity goes above the adjusted set point, and can control the EMC of lumber accurately enough to seldom need readjustment. For example, a 7 percent EMC can be maintained in a closed storage shed over a wide temperature range if the relative humidity is kept at about 35 percent.

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For example, a 7 percent EMC can be maintained in a closed storage shed over a wide temperature range if the relative humidity is kept at about 35 percent. Kiln-dried lumber is often stored in cooling sheds pending removal for factory processing or shipment.

Cooling sheds may be either open sheds or closed, unheated sheds. Excessive moisture regain can occur when open cooling sheds are used for temporary lumber storage. However, open cooling sheds can be converted to closed sheds; if this is done, humidistat control of heated, circulated air is often desirable. Such humidistat control will maintain low moisture levels indefinitely in kiln-dry lumber.

Closed, heated sheds are seldom insulated because generally they are heated only 10 or 15 degrees above the temperature of the outside air. Such a temperature elevation will usually protect even kiln-dry lumber from moisture regain. If closed, heated sheds are used for air drying, the shed should not be so tight that all air exchange with the outside is prevented. In that event, humidity from the drying lumber would elevate the EMC and defeat the purposes of the heating.

An efficient yard layout should provide good drainage of rain and melting snow, free movement of air in and out of the yard, and easy transportation and piling of lumber.

A yard laid out for rapid drying potential should be on high, well drained ground with no obstructions to prevailing winds. However, the need to keep the yard close to the plant limits site selection, and convenient areas are not always favorable to rapidly air drying lumber and providing a minimum of degrade.

Yard sites bounded by buildings or with standing water or streams nearby should be avoided because this retards lumber drying. Most yards are laid out in a rectangular scheme. The alleys or roadways cross each other at right angles, and the areas occupied by the piles are rectangular.

Specific areas may be designated for certain species, grades, or thicknesses of lumber. The alleys serve as routes for transporting the lumber, as pathways for the movement of air through the yard, and as protection against the spread of fire. The alleys in an air-drying yard are classified as main and cross alleys.

Main alleys are for access to the lumber stacks and cross alleys are for access to the main alleys.

In large air drying yards, blocks or areas are often separated by still wider roadways or strips of land to protect the lumber from the spread of fire and to meet insurance requirements. These wide alleys are sometimes called fire alleys.

The sides of the lumber piles are parallel to the main alleys, which means air flows through the lumber stacks from one main alley to an adjacent main alley. Spaces between the sides and ends of the piles are also part of the yard layout. These spaces form additional passageways for air movement.

Yards can be oriented in either of two ways. The main alleys run north and south to obtain faster roadway drying after rain or faster snow melt. With this orientation, the roadways are exposed to solar radiation more than when the main alleys are oriented east and west, where the lumber piles shade the main alley roadways and retard roadway drying and snow melt. This orientation might be best suited for areas of high precipitation, especially snowfall. It is also desirable to orient the main alleys as close as possible to parallel with the prevailing winds. With this orientation, the wind can blow unimpeded through the main alleys. As a result of complex patterns of air velocities through adjacent main alleys, air pressure varies within, which causes air to flow through the lumber packages from one main alley to the next. If the prevailing winds are directly west–east, it is impossible to satisfy both the advantages of solar radiation and prevailing winds.

However, there is often a north–south component to prevailing winds that does allow some air flow parallel to the main alleys.

The problem with north–south main alley orientation and direct west–east winds is that drying from the first row of lumber stacks upwind increases the relative humidity of the air exiting that row, thus slowing the drying in rows

Between cutting and use, lumber will probably be stored a number of times: At the sawmill, during transport, at lumberyards, and at the construction site. During each of these storage periods, the goal of the manager or supervisor should be to minimize grade and footage losses.

At sawmills, green lumber is stored before being stacked for air drying or kiln drying, or before shipment.

Softwood sawmills store rough lumber before finishing in the planer mill. Once the lumber has been planned it is often stored indoors, but outdoor storage with protective packaging is also becoming common. At hardwood sawmills, green lumber is usually not stored long before snickering because of the danger of fungal staining.

Air-dry rough hardwood lumber is usually bulk-piled and stored in open sheds, or outdoors under a protective cover. Kiln-dry rough hardwood lumber usually awaits shipment or factory processing in closed sheds. Dry lumber at woodworking plants is most often stored in sheds, although unit packages of softwood lumber in waterproof wrap are stored out doors for limited periods.

4.2.2 Temporary Protection

Plastic-coated paper wrap for the unit packages of lumber (fig. 17) will adequately protect kiln-dried softwood lumber under short-term storage conditions such as the following: Longhaul transport on flatcars; interim storage at distribution centers; and short-term outdoor storage, such as at construction sites.

But coated paper wrapping should not be considered a substitute for storage sheds when long-term storage of dried lumber is involved. The wrap can deteriorate during long-term exposure. The fragility of paper wrap must also be taken into account during handling.

At the least, lumber which is stored outdoors for any length of time in a protective wrap should be periodically inspected, and rips in the wrap taped or otherwise mended.

Dilapidated wrapping that holds rainwater may increase moisture regain more than if the lumber had no protection.

To avoid such water retention and to avoid tearing during forklift handling, the bottom of wrapped packages is often left uncovered. However, dampness from ground water can enter such packages if not enough ground clearance is provided by the pile foundation. The safe storage period with waterproof wrap will depend on the weather and upon the rate of wrapper deterioration due to exposure, mechanical handling, or damage by birds and animals.

Tarpaulins are often used for protecting bulked dry lumber temporarily stored outdoors. Water repellent-treated canvas, single-film polyethylene and laminated polyethylene films with scrim reinforcing are used as protective tarpaulins.

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➢ Lumber Storage Yards

The outdoor storage yard can be located at the sawmill, the wholesale or retail lumberyard, the custom kiln-drying plant, or the woodworking factory.

Conventional air drying is often practiced at such a yard. Thus the best location is on high, level ground which is well drained and not obstructed by trees or buildings.

A yard surface that is smooth and firm, particularly along the alleys, facilitates moving lumber packages. The yard layout should be oriented to the prevailing winds to accelerate the drying of stickered lumber. Vegetation can be controlled with weed killers. Routine maintenance should remove debris, which harbors stain and decay fungi and poses a fire hazard. An air-drying yard for storing stickered lumber packages is often laid out so that rows of piles run between main alleys. The rows may be short or long depending upon the amount of lumber to be stored in each row. A number of rows between cross alleys constitutes a lumber storage block.

Lumber Storage Yards

All piles of packages are accessible from the main alleys. The main alleys in both row-type and line-type forklift yards are usually 24 to 30 feet wide. The cross alleys are often as much as 60 feet wide to separate the blocks and check the spread of fire.

A lumber storage yard which is completely paved facilitates lift-truck operation and allows easier yard rearrangement with changes in lumber inventory.

➢ Use of Pile Covers

High-grade lumber stored in the yard, whether solid piled or stickered, should be protected from the weather. Lumber exposed to alternate wetting and drying will check, split, warp, and discolor. Piles of stickered lumber in the storage yard can be provided with pile covers as in conventional air-drying yards.

Pile covers of various designs and materials are placed on the pile’s top package before lifting that package into place.

Use of Pile Covers

Panel-type pile covers can also be used to roof stored, solid-stacked packages of rough or finished dry lumber. The covers must be rain tight and project beyond the pile ends and sidesto prevent rain entry into the bulked packages.

4.2.3. Timber piling/ stacking methods

Whether lumber should be solid piled or stickered depends upon its moisture content, intended use, and estimated duration of storage.

Lumber with an average moisture content of 20 percent or more which is to be held in storage for some time, particularly in warm weather, should be stickered as for conventional air drying. Such lumber is likely to seriously deteriorate if held very long in a solid pile.

Mold and stain will develop, followed by decay. If the moisture content of stored lumber averages less than 20 percent, mold, stain, and decay fungi will not grow. The intended use of this lumber, however, may be such that further drying is required.

If so, snickering for outdoor storage may effect further drying depending upon initial moisture content of the lumber and the prevailing climate.

Kiln-dried lumber will tend to regain moisture when stored outdoors, particularly during cool, damp periods. Thus solid piling may be preferable to snickering. But kiln-dry lumber which is solid piled must be protected from rain.

➢ The one and nine methods of stacking sleepers

Timber, before seasoning, should be stacked in yards free from weeds and debris. The yard should have big shady trees to protect the timber from direct sun.

Ends of logs should be protected against splitting by applying anti-splitting compositions and stacked on foundation in closed stacks in one or more layers. Stacks should be protected against direct sun by providing a covering – if needed.

It is best suited for moderately heavy coniferous sleepers in hot climate and for heavy timbers in moist climates.

➢ Close Crib method

In the close Crib method reduced air circulation slows down the pace of seasoning. This method is recommended for stacking heavy structural timbers in hot and dry localities.

Open Crib method

It is a modification of the close crib method and because of more air circulation taking place it is more akin to the one and nine method in its effects. Stacks of not more than 100 sleepers are recommended.

Poles are stacked either in closed heaps or with crossers. If stacked in closed heaps, then there should be alternate layers of butt ends and of top ends so that the two ends of the stack are level. Poles themselves could be used as crossers, which should not be spaced more than three metres.

➢ Open Crib method

Fence posts should be stacked in open crib fashion in which successive layers of posts are at right angles to each other and there is a gap of about 8 cm between adjacent posts in the same layer.

Centre to centre distance between crossers should not exceed 1.5 m and the height of stack should not exceed 3 metres.

➢ Timber stacking

Horizontal stacking of sawn timber is done on vertical pillars of treated timber, brick masonry or of cement concrete 30 cm square in section and 30 to 45 cm high. The pillars are spaced 1.2 m centre to centre along the length and the breadth of the stack.

The length of material to be stacked decides the length of stacking unit. Long beams of cross section 10 cm × 10 cm and above are placed on the foundation pillars to form a frame work for stacking timber. These beams should obviously be from strong timbers.

Scantling and squares should be stacked with crossers 5 cm × 4 cm in section and spaced 2.5 to 3 m apart. The ends should be protected with moisture proof coatings.

Planks should be stacked on level platform with crossers of uniform thickness and section, which (the crossers) should be in vertical alignment in a stack.

Longer planks should form the bottom of the stack and the shorter one's the top.

Heavy wooden beams should be placed on the top to prevent top layers from warping. A gap of about 2.5 cm should be left between adjoining planks for free circulation of air in the centre of stack. The stack should be protected against rain and sun by providing a shed over it.

Wood is an excellent material from functional, environmental and aesthetic points of view. It is renewable, can be re-used and re-cycled in certain applications and is biodegradable in others and it is used in different forms in the production of a wide range of products as well as being a source of energy.

Wood represents an important share of retailers' business. Embedding sustainable management for timber products means for retailers:

- To be recognized by customers as providers of sustainable products and services: customers value the engagement of companies towards sustainability, translated into increased reputation and customer loyalty.
- To raise general consumer awareness: due to the different aspects of sustainability that the timber issue involves, the existing sustainable approach in the timber supply chain can contribute to raising the awareness of consumers about sustainable consumption.
- Sustainable management of the timber supply chain offers a stimulus for companies to integrate sustainability in their broader corporate management.
- To protect and enhance timber resources: the long-term availability of wood as a resource can be promoted by ensuring sustainable forestry and by not sourcing from sensitive or high risk areas
- To enhance co-operation with partners: the sustainable management of forests and the legal harvesting and trade of timber are cross-sectoral initiatives that can enhance or create cooperation with NGOs, other partners (e.g. certification schemes) and other sectors (e.g. packaging and paper industries). This can bring benefits for the environment, consumers and the business itself.

In general, wood preservatives must meet two criteria:

- They must provide the desired wood protection in the intended end use, and
- They must do so without presenting unreasonable risks to people or the environment.

All wood preservatives are considered to be a type of pesticide; that's why they should be under control of the national government (rules, regulations and registration).

4. 3. Protect timber in storage

4.3.1. Types of preservative

➢ Waterborne preservative

Waterborne preservatives are often used when cleanliness and paintability of the treated wood are required. Formulations intended for use outdoors have shown high resistance to leaching and very good performance in service.

- Because water is added to the wood in the treatment process, some drying and shrinkage will occur after installation unless the wood is kiln-dried after treatment.
- Copper (C) is the primary biocide in many wood preservative formulations used in ground contact because of its excellent fungicidal properties and low toxicity.
- Because some types of fungi are copper tolerant, preservative formulations often include inorganic arsenicals or chromium which are a highly poisonous (CA, CCA).

➢ Oil-borne or oil-type preservatives

Oil-type wood preservatives are quite old and their use continues in many applications.

Wood does not swell from treatment with preservative oils, but it may shrink if it loses moisture during the treating process.

Creosote and solutions with heavy, less volatile petroleum oils often help protect wood from weathering but may adversely influence its cleanliness, odor, color, paintability, and fire performance.

Volatile oils or solvents with oil-borne preservatives, if removed after treatment, leave the wood cleaner than do the heavy oils but may not provide as much protection.

4.3. Selecting preservatives

The type of preservative applied is often dependent on the requirements of the specific application:

Direct contact with soil or water is considered a severe deterioration hazard, and preservatives used in these applications must have a high degree of leach resistance and efficacy against a broad spectrum of organisms.

These same preservatives may also be used at lower retentions to protect wood exposed in lower deterioration hazards, such as above the ground.

The exposure is less severe for wood that is partially protected from the weather, and preservatives that lack the permanence or toxicity to withstand continued exposure.

Other formulations may be so readily leachable that they can be used only indoors

4.3.1 Precautions for chemical application

- When select the preservative:
- When store the preservative:
- When apply the preservative:
- When the treated wood is in use:

4.3.2 Preparation of timber

For satisfactory treatment and good performance, the wood product must be sound and suitably prepared.

- The wood should be well peeled and either seasoned, dried or conditioned in the cylinder before treatment.
- It is also highly desirable that all machining be completed before treatment, including incising (to improve the preservative penetration in woods that are resistant to treatment/impregnation) and the operations of cutting or boring of holes.

4.3.3 Treatment methods

In commercial practice, wood is most often treated by immersing it in a preservative in a high-pressure apparatus and applying pressure to drive the preservative into the wood. Pressure processes differ in details, but the general principle is the same:

- The wood, on cars or trams, is run into a long steel cylinder, which is then closed and filled with preservative.
- Pressure forces the preservative into the wood until the desired amount has been absorbed. Considerable preservative is absorbed, with relatively deep penetration.
- Three pressure processes are commonly used: full cell, modified full cell, and empty cell.

➢ Full cell process

The full-cell (Bethel) process is used when the retention of a maximum quantity of preservative is desired.

It is a standard procedure for timbers to be treated with creosote when protection against marine borers is required.

Waterborne preservatives may be applied by the full-cell process if uniformity of penetration and retention is the primary concern.

Steps in the full-cell process are essentially the following:

- The charge of wood is sealed in the cylinder, and a preliminary vacuum is applied for a half-hour or more to remove the air from the cylinder and from the wood.
- The preservative, at ambient or elevated temperature depending on the system, is admitted to the cylinder without breaking the vacuum.
- After the cylinder is filled, pressure is applied until the wood will take no more preservative or until the required retention of preservative is obtained.
- When the pressure period is completed, the preservative is withdrawn.
- A short final vacuum may be applied to free the charge from dripping preservative.

➢ Modified full cell process

The modified full-cell process is basically the same as the full-cell process except for the amount of initial vacuum and the occasional use of an extended final vacuum.

The modified full-cell process uses lower levels of initial vacuum; the actual amount is determined by the wood species, material size, and final retention desired.

The modified full-cell process is commonly used for treatment of lumber with waterborne preservatives.

➢ Empty cell process

The empty-cell process is to obtain deep penetration.

For treatment with oil preservatives, the empty-cell process should always be used.

With poles and other products where bleeding of preservative oil is objectionable, the empty-cell process is followed by either heating in the preservative at a maximum of 104 °C (220 °F) or a final steaming for a specified time limit at a maximum of 116 °C (240 °F) prior to the final vacuum.

➢ Treating pressures and preservative temperatures

- The pressures used in treatments vary from about 345 to 1,723 kPa, depending on the species and the ease with which the wood takes the treatment. Most commonly, pressures range from about 862 to 1,207 kPa.
- The temperature of creosote and creosote solutions, as well as that of the oil-type preservatives, during the pressure period should not be greater than 100 °C.
- For CCA, a waterborne preservative that contains chromium, the maximum solution temperature is limited to 50 °C to avoid premature precipitation of the preservative.
- For most other waterborne preservatives, the maximum solution temperature is 65 °C, although a higher limit 93 °C is permitted for inorganic boron solutions.

➢ Nonpressure processes

Brief dipping

It is a common practice to treat window sash, frames, and other millwork, either before or after assembly, by dipping the item in a water-repellent preservative.

However, end penetration in such woods differ a lot (heartwood, sapwood etc.).

Transverse penetration of the preservative applied by brief dipping is very shallow, usually less than a millimeter.

Dip applications provide very limited protection to wood used in contact with the ground or under very moist conditions, and they provide very limited protection against attack by termites.

Cold-soaking

The methods of cold soaking well-seasoned wood for several hours or days in low-viscosity preservative oils or in waterborne preservatives have provided a range of success on fence posts, lumber, and timbers.

Preservative penetration and retention levels obtained by cold soaking lumber for several hours are better than those obtained by brief dipping of similar species.

However, preservative retention levels seldom equal those obtained in pressure treatment except in cases such as sapwood of pines that has become highly absorptive through mold and stain infection.

Vacuum process

The vacuum process, or “VAC–VAC” as referred to in Europe, has been used to treat millwork with water-repellent preservatives and construction lumber with water-borne and water-repellent preservatives.

In this treatment, a quick, low initial vacuum is followed by filling the cylinder under vacuum, releasing the vacuum and soaking, followed by a final vacuum.

In treating millwork, the objective is to use a limited quantity of water-repellent preservative and obtain retention and penetration levels similar to those obtained by 3-minute dipping.

Thermo treatment

Thermally modified timber (TMT) has a better biological stability compared to natural wood and does not need treatment with (poisonous) chemical preservatives.

The modification process combines high-temperature drying, thermal modification, cooling, and moisture conditioning.

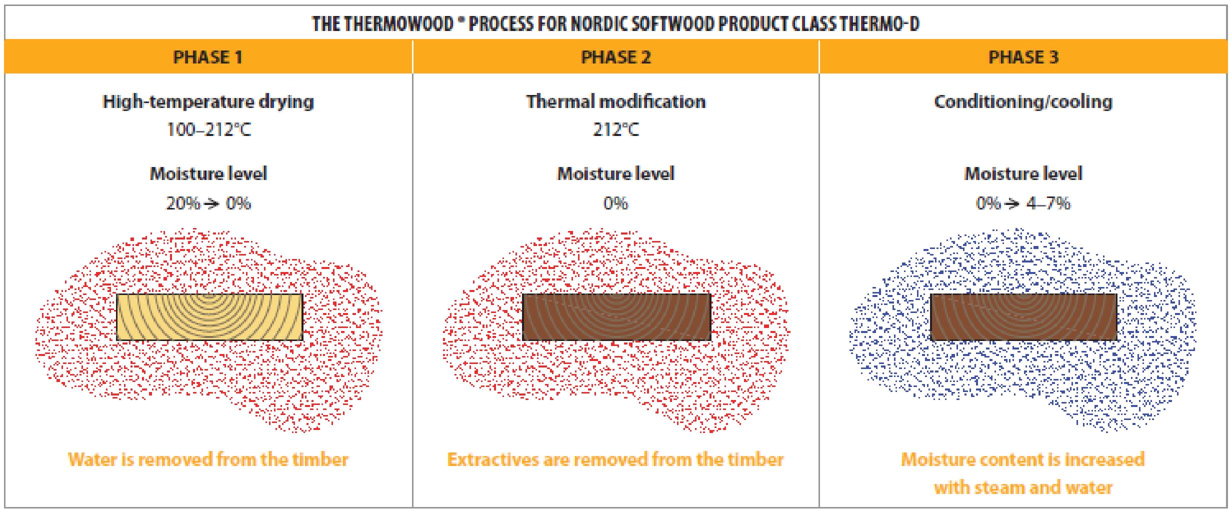
The modification temperature starts at 160 °C (max. 212 °C); so, a special “kiln” is needed for the process.

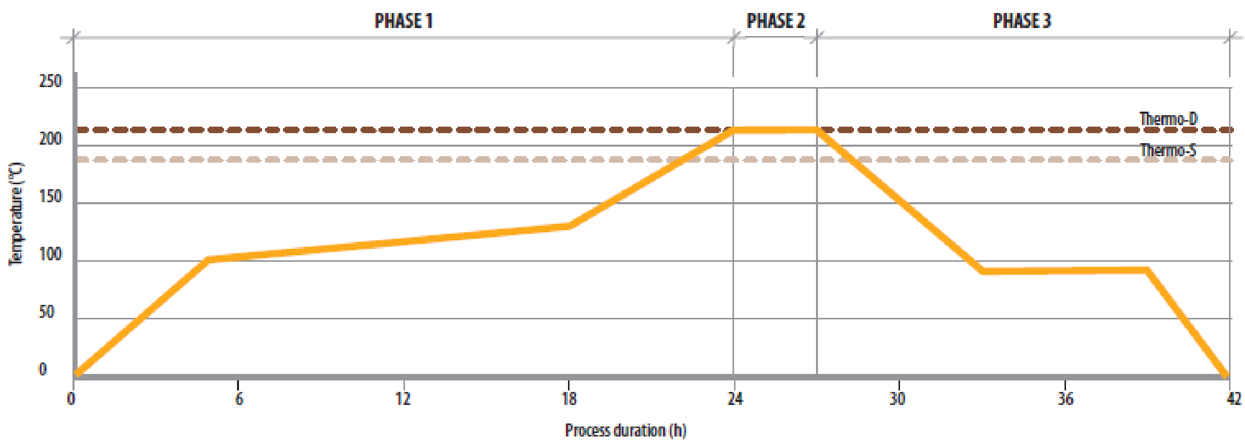
Manufacturing process of TMT

- Phase 1 – High-temperature drying: The kiln is heated rapidly to 100 °C. After this, the temperature is gradually increased to the desired level.
- Phase 2 – Thermal modification: After high-temperature drying, the kiln is maintained at a steady temperature and the actual modification takes place.
- Phase 3 – Cooling/conditioning: During the last phase, the temperature in the kiln is decreased with a water-spray system.

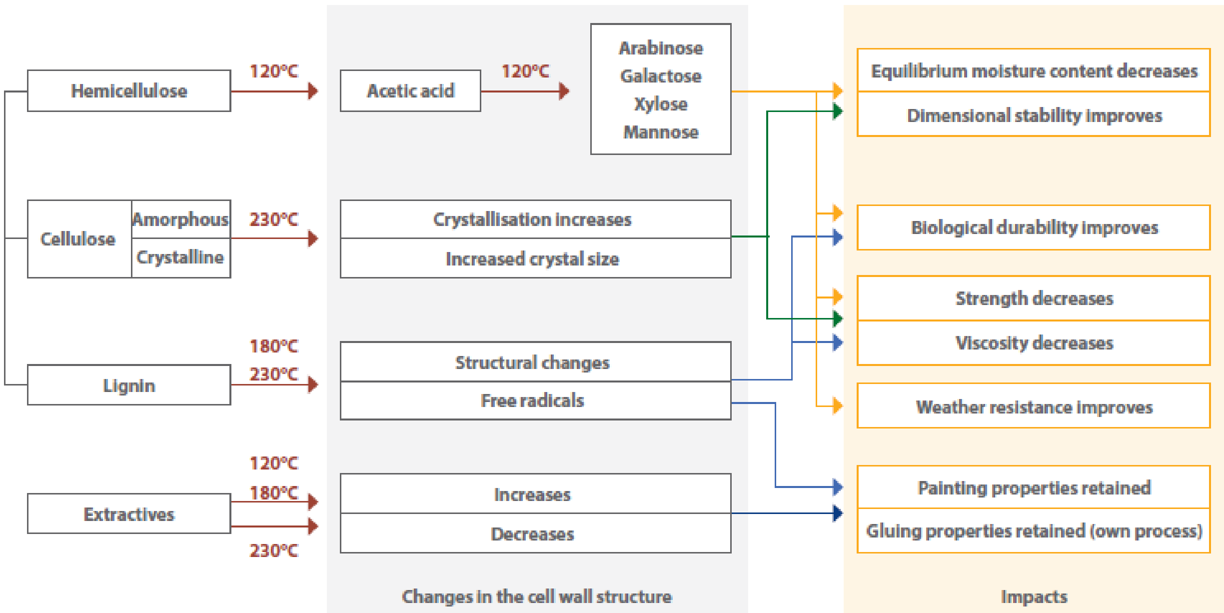
- When the temperature is sufficiently low, the timber's moisture content is increased using water and steam to improve its machinability and dimensional stability.

After the cooling phase, the moisture content of Thermo Wood® products is 4 to 7 %.





The changes in the wood structure are permanent



Impact on timber properties

Table 3. The impact of thermal modification on the timber's properties in the Thermo-D class.

Product class	Modification temperature	Property compared with that of untreated wood (+ = enhanced property) (++ = significantly enhanced property) (o = remains unchanged)		
		Weather resistance	Dimensional stability	Darkness
Thermo-D Nordic softwoods	212°C (+/- 3°C)	++	++	++
Thermo-230 °C Radiata pine	230°C (+/- 3°C)	++	++	++
Thermo-D Ayous (hardwood)	212°C (+/- 3°C)	+	+	++
Thermo-D Frake (hardwood)	212°C (+/- 3°C)	+	+	++
Thermo-D Ash (hardwood)	212°C (+/- 3°C)	+	+	++

Table 2. The impact of thermal modification on the timber's properties in the Thermo-S class.

Product class	Modification temperature	Property compared with that of untreated wood (+ = enhanced property) (++ = significantly enhanced property) (o = remains unchanged)		
		Weather resistance	Dimensional stability	Darkness
Thermo-S Nordic softwoods	190°C (+/- 3°C)	+	+	+
Thermo-S Radiata pine	190°C (+/- 3°C)	o	o	o
Thermo-S Hardwoods	185°C (+/- 3°C)	o	+	+

TMT is not recommended for structures that come into direct contact with soil or water.

The resistance to insect, beetle or termite attack is not yet fully explored.

Durability class (EN 350)	Use class (EN 335)	Examples of applications	ThermoWood® products
1 = Very durable	5 = Exposed to seawater 4 = Water contact	-	-
2 = Durable	3 = Outdoors, exposed to weather	Outdoor cladding Garden structures	Thermo-D, pine, spruce Thermo-D, ash, ayous, frake
3 = Moderately durable	2 = Outdoors, under roof	Sauna structures Outdoor structures and furniture under roof	Thermo-S, pine, spruce Thermo-S, hardwoods Thermo-D, hardwoods
4 = Little durable	1 = Indoors in dry conditions	Interior cladding	-

Impact on timber properties

- As properties like weather resistance and dimension stability increase, bending strength and modulus of elasticity decrease.
- Studies indicate that thermal modification reduces impact strength, compared with standard timber. Tests with spruce modified at 220 °C for three hours showed that the impact strength was reduced by about 25 %, compared with untreated wood.

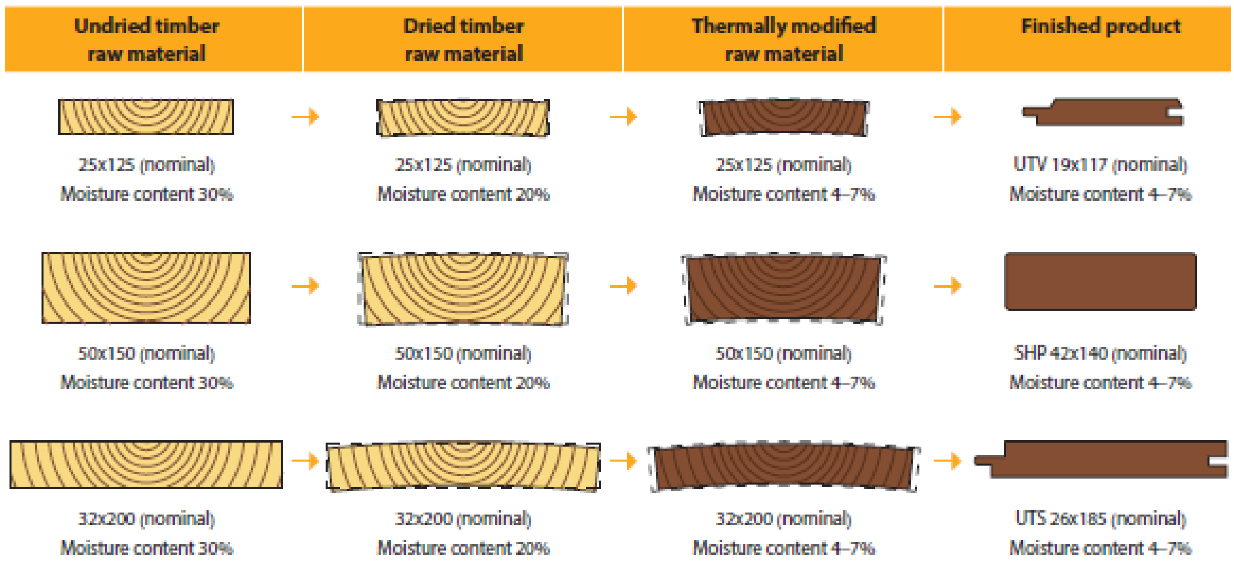



Figure 15. An example of a cladding panel (Nordic spruce).


Figure 16. An example of boards for sauna benches (Nordic spruce).


Figure 17. An example of a plank (Nordic spruce).


Figure 18. An example of a decking board (Nordic spruce).

4.3.4 Environmental protection of soil and water

Preservatives intended for use outdoors have mechanisms that are intended to keep the active ingredients in the wood and minimize leaching.

However, past studies indicate that a small percentage of the active ingredients of all types of wood preservatives leach out of the wood.

The amount of leaching depends on factors such as fixation conditions, preservative retention in the wood, product size and shape, type of exposure, and years in service.

4.3.5 Chemical hazards and risks for the workforce

All European manufacturers of chemical substances are obliged to register their goods with the European ECHA agency and to supply a so called Safety Data Sheet (SDS) at delivery. The SDS comprises all information about chemical hazards and risks for the workforce.

- Example: SDS of Wolmanit CX-8WB Wood Preservative

SAFETY DATA SHEET
according to Regulation (EC) No. 1907/2006

Wolman Wood and Fire Protection GmbH

Wolmanit CX-8WB

Version	Revision Date:	SDS Number:	Date of last issue: 05.10.2016
7.1	08.04.2021	000000442871	Date of first issue: 05.10.2016

SECTION 1: Identification of the substance/mixture and of the company/undertaking

1.1 Product identifier

Trade name : Wolmanit CX-8WB

Product code : 000000000050128694

1.2 Relevant identified uses of the substance or mixture and uses advised against

Use of the Substance/Mixture : wood preservative

Recommended restrictions on use : Industrial use, Professional use

1.3 Details of the supplier of the safety data sheet

Company : Wolman Wood and Fire Protection GmbH
Dr.-Wolman-Strasse 31-33
76547 Sinzheim

Telephone : +4972218000

Telefax : +497221800290

E-mail address of person responsible for the SDS : mabas-eb@mbcc-group.com

1.4 Emergency telephone

ChemTel: +1-813-248-0585

SECTION 2: Hazards identification

2.1 Classification of the substance or mixture

Classification (REGULATION (EC) No 1272/2008)

Acute toxicity, Category 4	H332: Harmful if inhaled.
Acute toxicity, Category 4	H302: Harmful if swallowed.
Skin corrosion, Category 1B	H314: Causes severe skin burns and eye damage.
Serious eye damage, Category 1	H318: Causes serious eye damage.
Reproductive toxicity, Category 2	H361d: Suspected of damaging the unborn child.
Specific target organ toxicity - single exposure, Category 3, respiratory tract irritation	H335: May cause respiratory irritation.
Hazardous to the aquatic environment - acute hazard, Category 1	H400: Very toxic to aquatic life.
Hazardous to the aquatic environment - chronic hazard, Category 2	H411: Toxic to aquatic life with long lasting effects.

2.2 Label elements

Labeling (REGULATION (EC) No 1272/2008)

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Hazard pictograms :

Signal Word : Danger

Hazard Statements :
H314 Causes severe skin burns and eye damage.
H332 Harmful if inhaled.
H302 Harmful if swallowed.
H335 May cause respiratory irritation.
H361d Suspected of damaging the unborn child.
H410 Very toxic to aquatic life with long lasting effects.

Precautionary Statements :

Prevention:
P260 Do not breathe dust/ fume/ gas/ mist/ vapors/ spray.
P273 Avoid release to the environment.
P280 Wear protective gloves/ protective clothing/ eye protection/ face protection.

Response:
P301 + P330 + P331 IF SWALLOWED: Rinse mouth. Do NOT induce vomiting.
P312 Call a POISON CENTER/ doctor if you feel unwell.
P303 + P361 + P353 IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water/ shower.
P305 + P351 + P338 IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
P308 + P313 IF exposed or concerned: Get medical advice/ attention.
P391 Collect spillage.

Storage:
P405 Store locked up.

Disposal:
P501 Dispose of contents/container to appropriate hazardous waste collection point.

Hazardous ingredients which must be listed on the label:
complexing agent based on ethanolamine and carboxylic acids (confidential)
copper(II) carbonate--copper(II) hydroxide(1:1)
Bis-(N-cyclohexyldiazeniumdioxy)-copper

2.3 Other hazards

This substance/mixture contains no components considered to be either persistent, bioaccumulative and toxic (PBT), or very persistent and very bioaccumulative (vPvB) at levels of 0.1% or higher.

If applicable information is provided in this section on other hazards which do not result in classification but which may contribute to the overall hazards of the substance or mixture.

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SECTION 3: Composition/information on ingredients

3.2 Mixtures

Chemical nature : Liquid wood preservative, based on:
Copper compound

dissolved in:
complexing agent based on ethanolamine and carboxylic acids (confidential)

Components

Chemical name	CAS-No. EC-No. Index-No. Registration number	Classification	Concentration (% w/w)
copper(II) carbonate--copper(II) hydroxide(1:1)	12069-69-1 235-113-6 01-2119429040-56	Acute Tox. 4; H332 Acute Tox. 4; H302 Eye Irrit. 2; H319 Aquatic Acute 1; H400 Aquatic Chronic 1; H410 M-Factor (Acute aquatic toxicity): 10 M-Factor (Chronic aquatic toxicity): 1	13,04
Bis-(N-cyclohexyldiazeniumdioxy)-copper	312600-89-8	Flam. Sol. 1; H228 Acute Tox. 4; H302 Eye Dam. 1; H318 STOT RE 2; H373 Aquatic Acute 1; H400 Aquatic Chronic 1; H410 M-Factor (Acute aquatic toxicity): 1 M-Factor (Chronic aquatic toxicity): 1	2,8
complexing agent based on ethanolamine and carboxylic acids (confidential)	Not Assigned	Acute Tox. 4; H332 Acute Tox. 4; H302 Skin Corr. 1B; H314 Repr. 2; H361d	>= 20 - <= 50

For explanation of abbreviations see section 16.

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SECTION 4: First aid measures

4.1 Description of first-aid measures

General advice : First aid personnel should pay attention to their own safety. Immediately remove contaminated clothing.

If inhaled : If difficulties occur after vapour/aerosol has been inhaled, remove to fresh air and seek medical attention.

In case of skin contact : After contact with skin, wash immediately with plenty of water and soap.
Under no circumstances should organic solvent be used.
If irritation develops, seek medical attention.

In case of eye contact : Wash affected eyes for at least 15 minutes under running water with eyelids held open, consult an eye specialist.

If swallowed : Immediately rinse mouth and then drink 200-300 ml of water, seek medical attention.
Do not induce vomiting unless told to by a poison control center or doctor.

4.2 Most important symptoms and effects, both acute and delayed

Symptoms : Information, i.e. additional information on symptoms and effects may be included in the GHS labeling phrases available in Section 2 and in the Toxicological assessments available in Section 11.

4.3 Indication of any immediate medical attention and special treatment needed

Treatment : Treat according to symptoms (decontamination, vital functions), no known specific antidote.

SECTION 5: Firefighting measures

5.1 Extinguishing media

Suitable extinguishing media : Foam
Water spray
Dry powder
Carbon dioxide (CO2)

Unsuitable extinguishing media : water jet

5.2 Special hazards arising from the substance or mixture

Hazardous combustion products : nitrogen oxides
fumes/smoke
carbon black
corrosive gases/vapours
Carbon oxides

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5.3 Advice for firefighters

Special protective equipment for fire-fighters : Wear a self-contained breathing apparatus.

Further information : The degree of risk is governed by the burning substance and the fire conditions.
Contaminated extinguishing water must be disposed of in accordance with official regulations.

SECTION 6: Accidental release measures

6.1 Personal precautions, protective equipment and emergency procedures

Personal precautions : Use personal protective clothing.
Do not breathe vapours/aerosols/spray mists.
Handle in accordance with good industrial hygiene and safety practice.

6.2 Environmental precautions

Environmental precautions : Contain contaminated water/firefighting water.
Do not allow to enter soil, waterways or waste water channels.

6.3 Methods and material for containment and cleaning up

Methods for cleaning up : Pick up with suitable absorbent material (e.g. sand, sawdust, general-purpose binder, kieselguhr).
Dispose of absorbed material in accordance with regulations.
Large spills should be collected mechanically (remove by pumping) for disposal.

6.4 Reference to other sections

For disposal considerations see section 13., For personal protection see section 8.

SECTION 7: Handling and storage

7.1 Precautions for safe handling

Advice on safe handling : Avoid contact with the skin, eyes and clothing.
Smoking, eating and drinking are forbidden in application areas. For personal protection see section 8. Comply with the health and safety at work laws.
Ensure thorough ventilation of stores and work areas.

Advice on protection against fire and explosion : No special precautions necessary.

Hygiene measures : When using, do not eat, drink or smoke. Hands and/or face should be washed before breaks and at the end of the shift. At the end of the shift the skin should be cleaned and skin-care agents applied. Gloves must be inspected regularly and prior to each use. Replace if necessary (e.g. pinhole leaks).

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7.2 Conditions for safe storage, including any incompatibilities

Further information on storage conditions : Keep only in the original container in a cool, dry, well-ventilated place away from ignition sources, heat or flame. Protect from direct sunlight. Store protected against freezing. Frost sensitive

7.3 Specific end use(s)

Specific use(s) : For the relevant identified use(s) listed in Section 1 the advice mentioned in this section 7 is to be observed.

SECTION 8: Exposure controls/personal protection

8.1 Control parameters

Occupational Exposure Limits

Components	CAS-No.	Value type (Form of exposure)	Control parameters	Basis
2-aminoethanol	141-43-5	TWA	1 ppm 2,5 mg/m3	2006/15/EC
	Further information: Indicative, Identifies the possibility of significant uptake through the skin			
		STEL	3 ppm 7,6 mg/m3	2006/15/EC
	Further information: Indicative, Identifies the possibility of significant uptake through the skin			
		TWA	1 ppm 2,5 mg/m3	GB EH40
	Further information: Can be absorbed through the skin. The assigned substances are those for which there are concerns that dermal absorption will lead to systemic toxicity.			
		STEL	3 ppm 7,6 mg/m3	GB EH40
	Further information: Can be absorbed through the skin. The assigned substances are those for which there are concerns that dermal absorption will lead to systemic toxicity.			
		TWA value	1 ppm 2,5 mg/m3	WEL/EH 40 (UK)
		STEL value	3 ppm 7,6 mg/m3	WEL/EH 40 (UK)
		STEL value	3 ppm 7,6 mg/m3	OEL (EU)
		TWA value	1 ppm 2,5 mg/m3	OEL (EU)

8.2 Exposure controls

Personal protective equipment

Eye protection : Tightly fitting safety goggles (splash goggles) (e.g. EN 166)

Hand protection

Remarks : Suitable chemical resistant safety gloves (EN 374) also with

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Notes

Group discussion:

- Which points did you find on these pages, regarding chemical hazards and risks for the workforce?
- ...
- ...
- ...

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prolonged, direct contact (Recommended: Protective index 6, corresponding > 480 minutes of permeation time according to EN 374): E.g. nitrile rubber (0.4 mm), chloroprene rubber (0.5 mm), butyl rubber (0.7 mm) etc. Manufacturer's directions for use should be observed because of great diversity of types.

Skin and body protection : Body protection must be chosen based on level of activity and exposure.

Respiratory protection : Wear respiratory protection if ventilation is inadequate.
Combination filter for gases/vapours of organic, inorganic, acid inorganic and alkaline compounds (e.g. EN 14387 Type ABEK).

Protective measures : Do not inhale gases/vapours/aerosols.
Avoid contact with the skin, eyes and clothing.
Handle in accordance with good industrial hygiene and safety practice.
Wearing of closed work clothing is recommended.

SECTION 9: Physical and chemical properties

9.1 Information on basic physical and chemical properties

Physical state : liquid
Color : blue
Odor : faint specific odour
Melting temperature : No data available

boiling temperature : > 100 °C
Flammability : Not applicable

Lower explosion limit / Lower flammability limit : dropped

Flash point : > 100 °C

Decomposition temperature
Decomposition temperature : > 250 °C
pH : approx. 9,6

Viscosity
Viscosity, dynamic : approx. 30 mPa.s (20 °C)

Solubility(ies)
Water solubility : completely miscible

Vapor pressure : Not applicable

Density : approx. 1,2 g/cm3 (20 °C)

9.2 Other information

Explosives : Not explosive

Oxidizing properties : not fire-propagating

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Miscibility with water : miscible in all proportions
20 °C

SECTION 10: Stability and reactivity

10.1 Reactivity

No hazardous reactions if stored and handled as prescribed/indicated.

10.2 Chemical stability

The product is stable if stored and handled as prescribed/indicated.

10.3 Possibility of hazardous reactions

Hazardous reactions : The product is stable if stored and handled as prescribed/indicated.

10.4 Conditions to avoid

Conditions to avoid : See SDS section 7 - Handling and storage.

10.5 Incompatible materials

Materials to avoid : Strong oxidizing agents
Strong reducing agents

10.6 Hazardous decomposition products

No hazardous decomposition products if stored and handled as prescribed/indicated.

SECTION 11: Toxicological information

11.1 Information on hazard classes as defined in Regulation (EC) No 1272/2008

Acute toxicity

Harmful if swallowed or if inhaled.

Product:

Acute oral toxicity : LD50 (Rat): approx. 500 mg/kg
Method: OECD Test Guideline 401

Acute dermal toxicity : LD50 (Rat): > 2.000 mg/kg
Method: OECD Test Guideline 402

Skin corrosion/irritation

Causes severe skin burns and eye damage.

Product:

Species : Rabbit
Assessment : Corrosive
Method : OECD Test Guideline 404

Serious eye damage/eye irritation

Causes serious eye damage.

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Product:
Species : Rabbit
Assessment : Risk of serious damage to eyes.
Method : OECD Test Guideline 405

Respiratory or skin sensitization

Skin sensitization
Not classified based on available information.

Respiratory sensitization
Not classified based on available information.

Product:
Test Type : Buehler test
Species : Guinea pig
Method : OECD Test Guideline 406
Result : Non-sensitizing.

Germ cell mutagenicity
Not classified based on available information.

Carcinogenicity
Not classified based on available information.

Reproductive toxicity
Suspected of damaging the unborn child.

STOT-single exposure
May cause respiratory irritation.

STOT-repeated exposure
Not classified based on available information.

Aspiration toxicity
Not classified based on available information.

11.2 Information on other hazards

Further information

Product:
Remarks : Based on our experience and the information available, no adverse health effects are expected if handled as recommended with suitable precautions for designated uses. The product has not been tested. The statements on toxicology have been derived from products of a similar structure and composition.

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SECTION 12: Ecological information

12.1 Toxicity

Product:
Toxicity to fish : LC50 (zebra fish): <= 1 mg/l
Exposure time: 96 h
Test Type: static
Method: OECD Test Guideline 203

Toxicity to daphnia and other aquatic invertebrates : LC50 (Daphnia magna (Water flea)): < 1 mg/l
Exposure time: 48 h
Test Type: static
Method: OECD Test Guideline 202

Toxicity to algae/aquatic plants : EC50 (green algae): < 1 mg/l
Exposure time: 72 h
Method: OECD Test Guideline 201

Toxicity to microorganisms : EC50 (activated sludge): approx. 50 mg/l
Exposure time: 3 h
Method: OECD Test Guideline 209

Components:

copper(II) carbonate--copper(II) hydroxide(1:1):
M-Factor (Acute aquatic toxicity) : 10

M-Factor (Chronic aquatic toxicity) : 1

Bis-(N-cyclohexyldiazeniumdioxy)-copper:
M-Factor (Acute aquatic toxicity) : 1

M-Factor (Chronic aquatic toxicity) : 1

12.2 Persistence and degradability

Product:
Biodegradability : Result: Moderately/partially biodegradable.
Remarks: The ingredients based on copper can be virtually eliminated from water by abiotic processes e.g. adsorption onto activated sludge.

12.3 Bioaccumulative potential

Product:
Bioaccumulation : Remarks: Accumulation in organisms is not to be expected.

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12.4 Mobility in soil

Product:
Distribution among environmental compartments : Remarks: Following exposure to soil, adsorption to solid soil particles is probable, therefore contamination of groundwater is not expected.

12.5 Results of PBT and vPvB assessment

Product:
Assessment : This substance/mixture contains no components considered to be either persistent, bioaccumulative and toxic (PBT), or very persistent and very bioaccumulative (vPvB) at levels of 0.1% or higher..

12.6 Endocrine disrupting properties
No data available

12.7 Other adverse effects

Product:
Ozone-Depletion Potential : Remarks: The product does not contain substances that are listed in Regulation (EC) 1005/2009 on substances that deplete the ozone layer.

Additional ecological information : The product should not be allowed to reach either sewage waters or water purification plants.
The product has not been tested. The statements on ecotoxicology have been derived from products of a similar structure and composition.

SECTION 13: Disposal considerations

13.1 Waste treatment methods
Product : The UK Environmental Protection (Duty of Care) Regulations (EP) and amendments should be noted (United Kingdom).
This product and any uncleaned containers must be disposed of as hazardous waste in accordance with the 2005 Hazardous Waste Regulations and amendments (United Kingdom).

This material and its container must be disposed of in a safe way.
Must be disposed of or incinerated in accordance with local regulations.

Contaminated packaging : Contaminated packaging should be emptied as far as possible; then it can be passed on for recycling after being thoroughly cleaned.

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SECTION 14: Transport information

14.1 UN number or ID number
ADN : UN 1760
ADR : UN 1760
RID : UN 1760
IMDG : UN 1760
IATA : UN 1760

14.2 UN proper shipping name
ADN : CORROSIVE LIQUID, N.O.S. (ALKYLAMINE, COPPER CARBONATE)
ADR : CORROSIVE LIQUID, N.O.S. (ALKYLAMINE, COPPER CARBONATE)
RID : CORROSIVE LIQUID, N.O.S. (ALKYLAMINE, COPPER CARBONATE)
IMDG : CORROSIVE LIQUID, N.O.S. (ALKYLAMINE, COPPER CARBONATE)
IATA : CORROSIVE LIQUID, N.O.S. (ALKYLAMINE, COPPER CARBONATE)

14.3 Transport hazard class(es)
ADN : 8
ADR : 8
RID : 8
IMDG : 8
IATA : 8

14.4 Packing group

ADN
Packing group : II
Labels : 8

ADR
Packing group : II
Hazard Identification Number : 80
Labels : 8
Tunnel restriction code : (E)

RID
Packing group : II
Hazard Identification Number : 80
Labels : 8

IMDG
Packing group : II
Labels : 8

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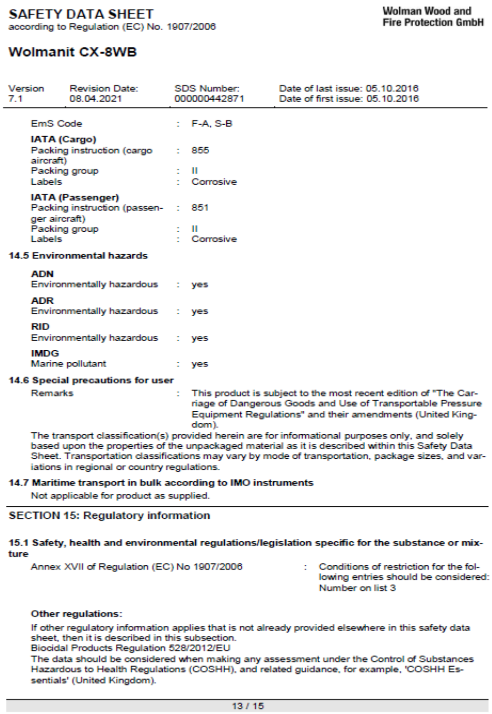
Notes

Group discussion:

- Which points did you find on these pages, regarding chemical hazards and risks for the workforce?
- ...
- ...
- ...



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EmS Code : F-A, S-B

IATA (Cargo)
Packing instruction (cargo aircraft) : 855
Packing group : II
Labels : Corrosive

IATA (Passenger)
Packing instruction (passenger aircraft) : 851
Packing group : II
Labels : Corrosive

14.5 Environmental hazards

ADN
Environmentally hazardous : yes

ADR
Environmentally hazardous : yes

RID
Environmentally hazardous : yes

IMDG
Marine pollutant : yes

14.6 Special precautions for user

Remarks : This product is subject to the most recent edition of "The Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations" and their amendments (United Kingdom).

The transport classification(s) provided herein are for informational purposes only, and solely based upon the properties of the unpackaged material as it is described within this Safety Data Sheet. Transportation classifications may vary by mode of transportation, package sizes, and variations in regional or country regulations.

14.7 Maritime transport in bulk according to IMO instruments

Not applicable for product as supplied.

SECTION 15: Regulatory information

15.1 Safety, health and environmental regulations/legislation specific for the substance or mixture

Annex XVII of Regulation (EC) No 1907/2006 : Conditions of restriction for the following entries should be considered: Number on list 3

Other regulations:

If other regulatory information applies that is not already provided elsewhere in this safety data sheet, then it is described in this subsection.
Biocidal Products Regulation 528/2012/EU
The data should be considered when making any assessment under the Control of Substances Hazardous to Health Regulations (COSHH), and related guidance, for example, 'COSHH Essentials' (United Kingdom).

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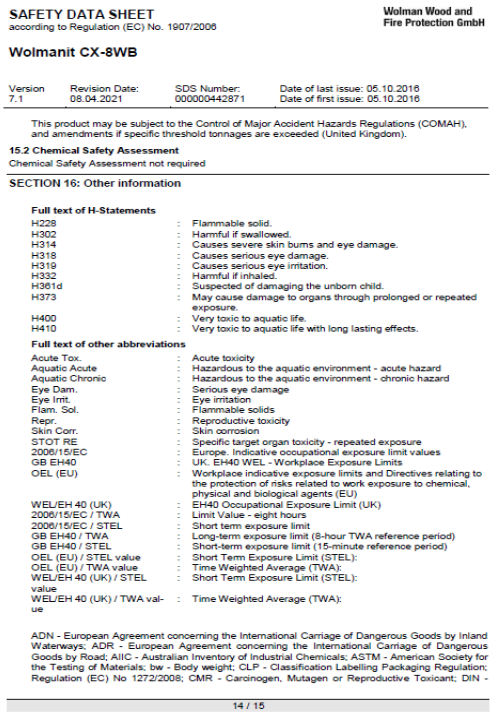

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This product may be subject to the Control of Major Accident Hazards Regulations (COMAH), and amendments if specific threshold tonnages are exceeded (United Kingdom).

15.2 Chemical Safety Assessment

Chemical Safety Assessment not required

SECTION 16: Other information

Full text of H-Statements

H228 : Flammable solid.
H302 : Harmful if swallowed.
H314 : Causes severe skin burns and eye damage.
H318 : Causes serious eye damage.
H319 : Causes serious eye irritation.
H332 : Harmful if inhaled.
H361d : Suspected of damaging the unborn child.
H373 : May cause damage to organs through prolonged or repeated exposure.
H400 : Very toxic to aquatic life.
H410 : Very toxic to aquatic life with long lasting effects.

Full text of other abbreviations

Acute Tox. : Acute toxicity
Aquatic Acute : Hazardous to the aquatic environment - acute hazard
Aquatic Chronic : Hazardous to the aquatic environment - chronic hazard
Eye Dam. : Serious eye damage
Eye Irrit. : Eye irritation
Flam. Sol. : Flammable solids
Repr. : Reproductive toxicity
Skin Corr. : Skin corrosion
STOT RE : Specific target organ toxicity - repeated exposure
2006/15/EC : Europe. Indicative occupational exposure limit values
GB EH40 : UK. EH40 WEL - Workplace Exposure Limits
OEL (EU) : Workplace indicative exposure limits and Directives relating to the protection of risks related to work exposure to chemical, physical and biological agents (EU)
WEL/EH 40 (UK) : EH40 Occupational Exposure Limit (UK)
2006/15/EC / TWA : Limit Value - eight hours
2006/15/EC / STEL : Short term exposure limit
GB EH40 / TWA : Long-term exposure limit (8-hour TWA reference period)
GB EH40 / STEL : Short-term exposure limit (15-minute reference period)
OEL (EU) / STEL value : Short Term Exposure Limit (STEL):
OEL (EU) / TWA value : Time Weighted Average (TWA):
WEL/EH 40 (UK) / STEL value : Short Term Exposure Limit (STEL):
WEL/EH 40 (UK) / TWA value : Time Weighted Average (TWA):

ADN - European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways; ADR - European Agreement concerning the International Carriage of Dangerous Goods by Road; AIIC - Australian Inventory of Industrial Chemicals; ASTM - American Society for the Testing of Materials; bw - Body weight; CLP - Classification Labelling Packaging Regulation; Regulation (EC) No 1272/2008; CMR - Carcinogen, Mutagen or Reproductive Toxicant; DIN -

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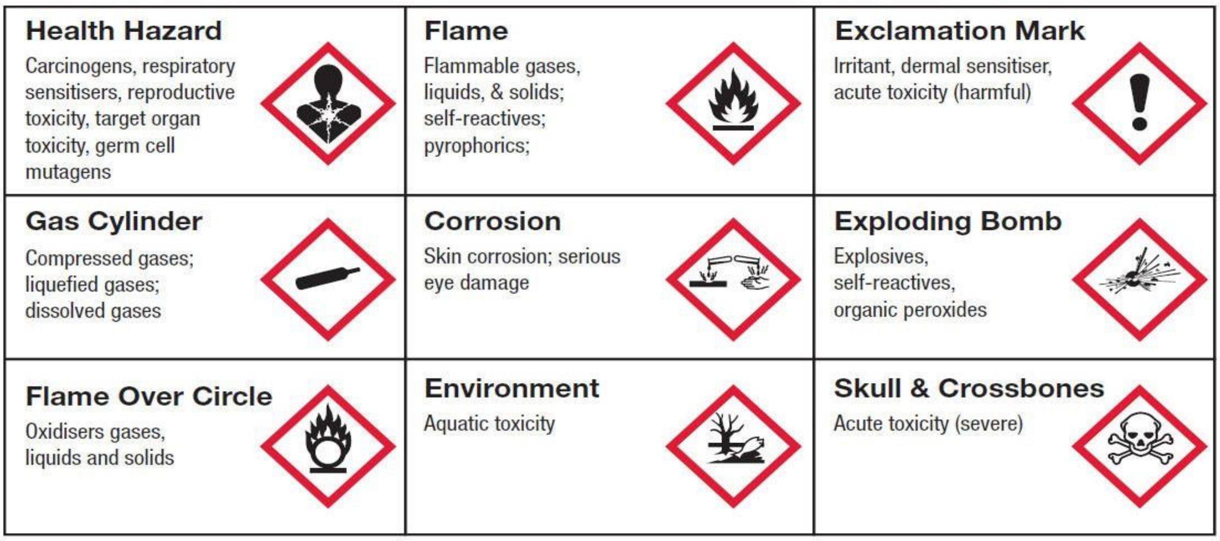
Globally Harmonized System of Classification and Labelling



➢ Standards about preservative treatment of timber

Example: Draft Ugandan Standard DUS 2021"Preservative Treatment of Timber"

This standard covers the classification of timber preservatives, hazard conditions for timber, the solvents used for timber preservatives, the preparation of timber for treatment, the various treatment processes and the use of preservative-treated timber in specific areas in Uganda.

Recommendations relating to the handling and safety of preservative-treated timber are also given

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3. https://civiltoday.com/civil-engineering-materials/timber/85-defects-in-timber-types-and-reasons
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20. Braun (of Germany) https://braun-maschinen.de/produktseite-t1standard/
21. EBERL (of Germany) https://www.eberl-trocknungsanlagen.de/index.html
22. EIP / EBAC (of UK/USA) http://www.ebacusa.com/lumber_dryers.html
23. ETEGO (of Germany)https://etego-gmbh.de/leistungen/holz-prozesstrocknung/
24. LAUBER (of Germany)https://www.lauber-holztrockner.de/en/products/timber-dryers/lauber-longitudinal-wood-dryer
25. https://www.nyle.com/kiln-drying-systems/lumber-kiln-drying/dehumidification-kilns/lt-dh-systems/
26. PARMATAM (of Belgium)https://parmatam-en.weebly.com/
27. SOLAR DRYERS AUSTRALIAhttp://www.solardry.com.au/solardry/10m.html
28. SOLARKILNS (of Australia)https://solarkilns.com/
29. Wood-Mizer (of USA) https://woodmizer.com/Store/Shop/Kiln-Lumber-Drying/Solar-Kiln-Kit.

Additional references and sources of information online (free of charge)

Technical reports of the Forest Service of the United States Department of Agriculture and its Forest Products Laboratory (FPL) at Madison, Wisconsin 53726; https://www.fpl.fs.fed.us/index.php

- Drying Hardwood Lumber; https://www.fpl.fs.fed.us/documnts/fplgtr/fplgtr118.pdf
- Air Drying of Lumber; https://www.fpl.fs.fed.us/documnts/fplgtr/fplgtr117.pdf
- Dry Kiln Operator's Manual, 1991 and revised edition 2001; http://www.tropicaltimber.info/wp-content/uploads/2015/09/USDA.FPL_.AH188.Rev1991DryKilnOperatorsManual.pdf https://www.fpl.fs.fed.us/products/publications/several_pubs.php?grouping_id=101&header_id=p
- Dry Kiln Schedules for Commercial Woods; https://www.fpl.fs.fed.us/documnts/fplgtr/fplgtr57.pdf
- Wood Handbook – Wood as an Engineering Material; https://www.fpl.fs.fed.us/documnts/fplgtr/fpl_gtr190.pdf
- Operation and Cost of a Small Dehumidification Dry Kiln; https://www.fpl.fs.fed.us/documnts/fplrn/fpl_rn310.pdf

Free of charge series of YouTube videos on lumber drying at the web-site of NHLA National Hardwood Lumber Association of the U.S.; https://www.nhla.com/education/webinars/

- Part 1: Moisture Content Measurement During Drying; https://youtu.be/eOzSrTh5Lwc
- Part 2: Storage of KD Lumber & Powderpost Beetle Control; https://youtu.be/i8cEYXY0e2Q
- Part 3: Kiln Schedules & Four Stages of Drying; https://youtu.be/Eih_T1fFVQg
- Part 4: Causes and Cures for Drying Defects; https://youtu.be/2zIgKrgAQqw
- Part 5: Air Drying & Shed Drying; https://youtu.be/ag-8ykvnklg

Free of charge short video clips about MC and moisture management produced by Wagner meters; https://www.wagnermeters.com/moisture-meters/wood-moisture-training/wood-doctor-videos/

- Video 1: Wood's Relationship and Reaction to Moisture; https://youtu.be/Nf3YDl9DO0E
- Video 2: Relative Humidity and Moisture Content; https://youtu.be/ZsN14G_0sls
- Video 3: Problems Associated with Incorrect Moisture Content; https://youtu.be/SIjH0U-clzU

- Video 4: Interior MC of Homes and Offices in North America; https://youtu.be/TotSOO34zDQ
- Video 5: Storing Wood at the Correct MC or EMC; https://youtu.be/TY-Jw0JPv40
- Video 6: How to Correct Wood Moisture Content; https://youtu.be/ViaNm8QIRp4
- Video 7: Definition of MC and Verification of Actual MC; https://youtu.be/P6TzlaHUsgs

Manuals of the Forest & Wood Products Australia Association (FWPA) which might be of special interest when it comes to drying of eucalyptus; https://fwpa.com.au

- Australian Hardwood Drying Best Practice Manual, Part 1;
- https://www.fwpa.com.au/images/processing/tdm%20part1%20WEB.pdf
- Australian Hardwood Drying Best Practice Manual, Part 2; https://www.fwpa.com.au/images/processing/tdm%20part2%20WEB.pdf

Oregon State University OSU online courses about lumber drying and its “ScholarsArchive”;

- https://workspace.oregonstate.edu/course/Lumber-Drying-Online-Workshop?hsLang=en
- https://ir.library.oregonstate.edu/?locale=en