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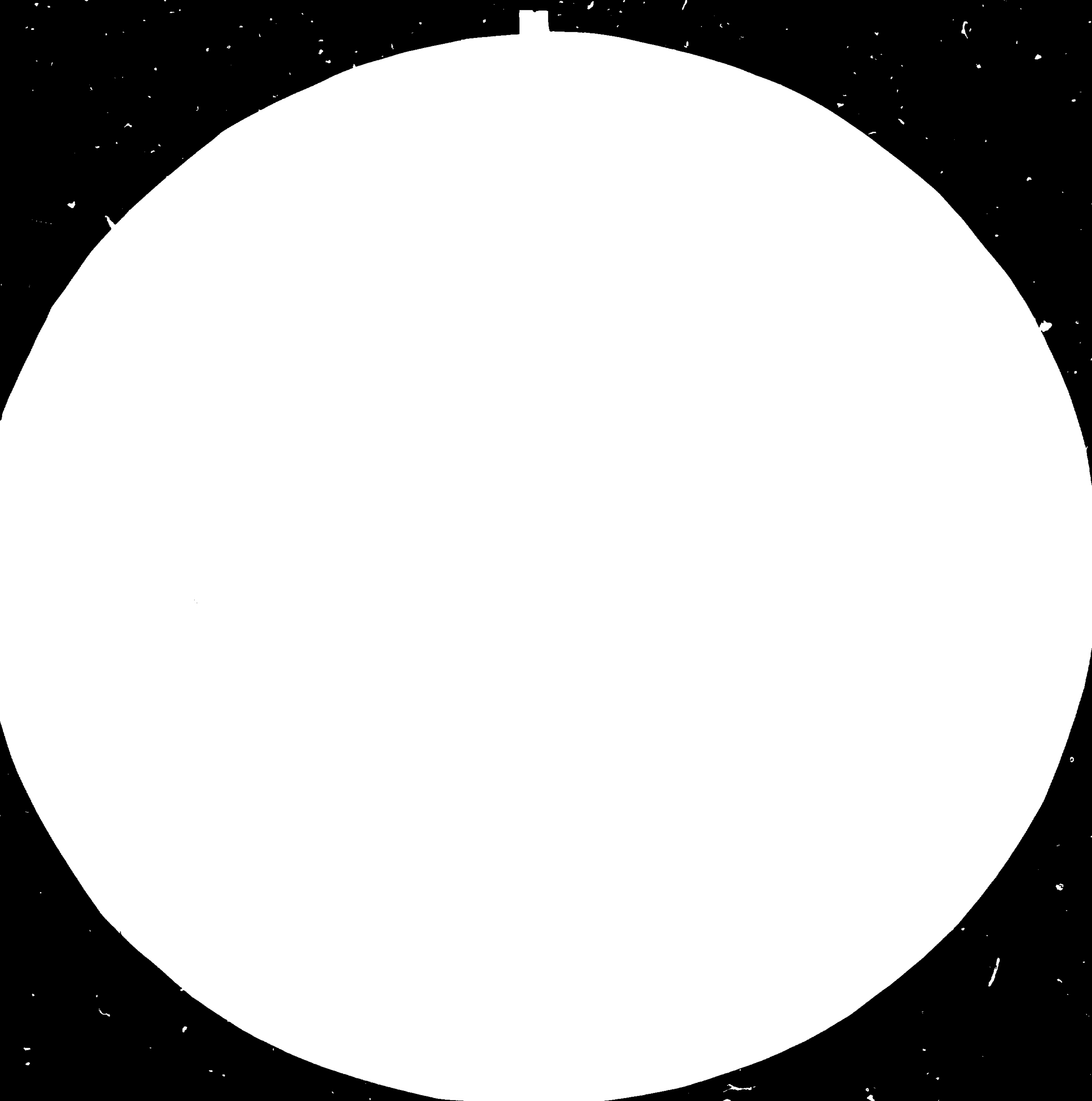

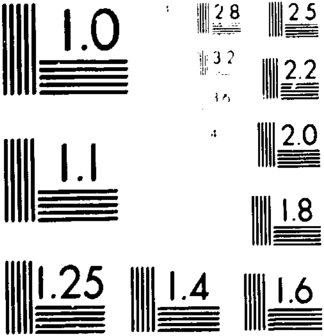

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WHY AND HOW WOOD DRIES *

by

R. Cividini

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1. WHY AND HOW WOOD DRIES

Some problems involved in the operation of driers and drying processes.

The main thrust behind the development of modern wood-drying techniques has been derived from new contributions to our knowledge of the physical nature of wood and of its drying processes.

Generally, softwood has a relatively dry duramen (water content 100 Kg/m^3, moisture 31-35%), while its sapwood has a high moisture content (570 Kg/m^3, 120-160%). Exceptions: Weymouth pine with heartwood moisture averaging 80%, and the "wet heartwood" of the Silver Fir reaching up to 220% (800 Kg/m^3) where present. Hardwood is moister and the differences between the moisture content of the sapwood and of the duramen are less marked[1/]. Generally, the wood gets moister as one moves toward the top, because the sapwood prevails in this area. Moisture diminishes with age, hence the wood supplied by young forests is damper than the one obtained from mature ones; similarly, wood coming from trees of different ages are usually moister than wood coming from forests in which trees are all of the same age.

Part of the water contained in the wood runs freely in the cellular and intercellular cavities (free water), the rest, however, is enclosed by the cell walls (hygroscopic humidity). Hygroscopic humidity accounts for 30 to 38% of the weight of the dry ligneous substance (saturation point of the cell walls).

[1/] The humidity of fresh wood, e. g., beechwood is included between 80 and 90%, which means a water content of 450-500 Kgs for each cubic m. of wood, while the degree of humidity of poplar-wood may exceed even 200% (i. e., more than 600 Kgs of water in each cubic m. of wood.

In an unsaturated environment (unsaturated air), free humidity (i. e., the one which exceeds the saturation point of the walls) is subject to evaporation.

As to the water present in the cell walls, the wood may be considered a hygroscopic material, which means that it is subject to changes in humidity, with the environmental air. On a humidity scale ranging from 0 to the wall saturation point, the wood acquires a degree of moisture which is in equilibrium with a relative humidity and the temperature of the surrounding air (Table 1); if it is moister than the point of equilibrium it dries, if it is drier than the point of equilibrium it grows moist.

Table 1

Moisture at which wood stabilizes (moisture content equilibrium) as a function of the temperature and humidity of the surrounding air.

Relative Humidity of air as a % of saturation		Temperature of Air °C							
		0- 5	5-10	10-15	15-20	20-25	25-30	30-35	35-40
From	T o	Wood Moisture (Per Cent)							
20	25	5	5	5	5	5	5	5	5
25	30	6	6	6	6	6	6	5	5
30	35	7	7	7	7	7	6	6	6
35	40	8	7	7	7	7	7	7	7
40	45	8	8	8	8	8	8	8	7
45	50	9	9	9	9	9	9	8	8
50	55	10	10	10	10	10	9	9	9
55	60	11	11	11	10	10	10	10	10
60	65	12	12	12	11	11	11	11	11
65	70	13	13	13	12	12	12	12	12
70	75	14	14	14	14	13	13	13	13
75	80	16	16	15	15	15	15	14	14
80	85	18	18	17	17	17	17	16	16
85	90	20	20	20	19	19	19	18	18
90	95	23	22	22	22	22	21	21	21
95	100	27	26	26	26	26	26	25	25

The two processes are not wholly reversible and it has been established that, the difference in pressure being equal, the degree of moisture of the wood obtained through absorption is lesser than the one obtained through drying. This phenomenon, which is known as hysteresis, entails a 2-4% difference in wood moisture between the two respeetive processes and is explained "through the theory according to which a part of the OH remain linked to one another" and "through the reduction in wettability of the dry surfaces".

This phenomenon is associated with the fact that the drying speed is far greater than the water absorption speed. The wood, thus, presents a certain degree of hygroscopic inertia which is stronger for the rises than for the reductions in humidity.

When the hygroscopic humidity diminishes, the wood shrinks (i. e., it diminishes in size), when the former rises, the wood swells up again.

The anisotropy of the shrinkages, namely, the ratio among the three linear shrinkages, for the most types of wood is approximately:

$$\beta_I : \beta_r : \beta_t = 1 : 10 : 20$$

Shrinkages, too, are a specific feature of the wood species, though they extend over a rather wide range, even for samples of wood belonging to the same species.

Table 2 shows also the ratio between tangential shrinkage and radial shrinkage, which may be used as an index of wood deformability. The latter, in fact, increases with any increase in the $\frac{\beta_t}{\beta_r}$ ratio.

Table 2

Wood-air moisture content equilibrium and shrinkage-swelling in the 60% and 90% relative air moisture (R.H.) range with air temperature around 20°C (F.P.R.L. Princes Risborough), "Dimensional Instability" and "Deformability".

Ligneous Species	% per R.H.		Shrinkage-Swelling in 60% and 90% R.H. range: tangential		radial		dimens instability $\frac{k_t}{k_r}$	deformability $\frac{\Delta\beta_t}{\Delta\beta_r}$
	90%	60%	$\Delta\beta_t$	k_t *	$\Delta\beta_r$	k_r *		
Obeche (Wawa, Samba)	19	12	1.25	0.18	0.8	0.12	0.30	1.5
Afrormosia	15	11	1.3	0.32	0.7	0.17	0.49	1.9
Maple	23	13.5	2.8	0.29	1.4	0.15	0.44	1.9
Birch	21.5	12	2.5	0.26	2.2	0.23	0.49	1.1
Beech	20	12	3.2	0.40	1.7	0.21	0.61	1.9
Oak (Europe)	20	12	2.5	0.31	1.5	0.19	0.50	1.6
Ash	20	12.5	1.8	0.24	1.3	0.17	0.41	1.4
Iroco	15	11	1.0	0.25	0.5	0.12	0.37	2.0
Cherry	19	12.5	2.0	0.31	1.2	0.18	0.19	1.7
Larch (Europe)	19	13	1.7	0.28	0.8	0.13	0.41	2.1
Limba (Frakè)	18	12	1.3	0.22	1.0	0.17	0.39	1.3
Khaya grandifolia	23	14	1.9	0.21	1.5	0.17	0.38	1.2
Khaya ivorensis	20	13.5	1.5	0.23	0.9	0.14	0.37	1.6
Mahogany (Swietenia)	19	12.5	1.3	0.20	1.0	0.15	0.35	1.3
Makoré	19	13	1.8	0.30	1.1	0.18	0.48	1.7
Bété	20	12	2.3	0.29	1.3	0.16	0.45	1.8
African walnut	18	13	1.3	0.26	0.9	0.18	0.44	1.4
European walnut	18.5	11.5	2.0	0.29	1.6	0.23	0.52	1.3
Red oak	18.5	11.5	2.4	0.34	1.3	0.19	0.53	1.8
Elm	22	13	2.4	0.27	1.5	0.17	0.44	1.6
Sapeli	20.5	13.5	1.8	0.26	1.3	0.19	0.45	1.4
Teck and Padouk	15	10	1.3	0.26	0.8	0.16	0.42	1.6
Wengé	15	11.5	0.9	0.26	0.65	0.19	0.45	1.4
Abura	-	11.5	-	0.20	-	0.08	0.28	2.5
Sipo	20	14	-	0.20	-	0.15	0.35	1.3
Kosipo	22	15	-	0.18	-	0.13	0.31	1.4

[*] Shrinkage coefficients for a 1% loss of moisture of the wood between the moisture content equilibrium values shown in the table.

Practically, shrinkage begins when the average moisture content of the wood is considerably higher than 30%, because the outer layers start to yield their saturation moisture while the inner layers are still very damp.

The average degree of humidity marking the beginning of the shrinkage process depends, basically, on permeability, thickness, initial moisture content, intensity of drying, and mechanical resistance (plasticity when subjected to tension and to compression).

Finished wood products tend to adjust to the environment in which they are placed; their moisture content equilibrium should therefore be based on local climatic conditions so as to stabilize them in both their dimensions and their shape. This leads us to consider the relevant wood moisture regulations concerning products manufactured for different environments, exposures and microclimates (Table 3).

Recommended Final Wood Moisture for Some Products

	%
Commercial lumber	16 - 20
Building timber	12 - 18
Barrack timber	12 - 15
Panels (plywood, built-up boards, particle boards, etc.), veneering boards	6 - 8
Commercial veneerings	12 - 16
Cores for built-up boards	6 - 7
Outside frames	12 - 15
Inside frames	8 - 10
Parquetry floors and interior matchboarding	6 - 8
Furniture for interiors and sundry fittings	6 - 10
Furniture and tools to be used outdoors (for gardening, etc.)	12 - 16
Agricultural machines and coachwork	12 - 18
Motor-car coachwork	7 - 10
Railway carriages (internal parts)	6 - 8
Aircraft constructions	6 - 10
Watercrafts	12 - 16
Sporting equipment	8 - 12
Toys to be used indoors	6 - 10
Toys to be used outdoors	10 - 15
Wooden lasts	6 - 9
Rifle butts	7 - 12
Electrical equipment	5 - 8
Musical instruments	5 - 8
Dies	6 - 8
Frames	6 - 10
Casks, cases	12 - 16

Environmental conditions normally vary throughout the year in accordance with the different seasons and room conditioning equipment. If the variations do not exceed the hysteresis limits, wood moisture does not vary, as long as it has previously been treated in such a way that reaches the lower limit. Due to hygroscopic inertia, wood moisture does not vary even when subjected to occasional changes exceeding the above-mentioned limits. Hygroscopic inertia increases with the volumetric weight and thickness of the wood as well as with the degree of thoroughness with which the wood has been varnished and the water-repellent characteristics of the products used for treating the wood.

Any variation in the saturation moisture content results in dimensional changes and deformation of the wood (see Table 2 above). Through drying, therefore, relative stabilization is obtained.

Wood permeability is the single most important factor in the drying process. Radial permeability is considerably greater than tangential permeability; thus, lateral boards dry in considerably less time than central ones. Radial permeability increases with the size of the rays. Unfortunately, as the size and frequency of the rays increases, the resistance of the wood to transversal tensile stress diminishes and this, eventually, leads to clefts in the wood.

Unless the wood is soaked in water immediately, the drying process begins as soon as the tree is cut down, because the free water tends to evaporate from the surface of the wood (Phase I). As this process extends to ever-deeper levels - through the diffusion of the vapour which develops in depth as a result of wood porosity and, partly, of capillary movement in permeable wood - a fairly regular parabolic gradient for thickness moisture is obtained even before reaching the first critical point. In wood characterized by medium permeability, vapour diffusion and capillary movements are more limited, and the water tends to be diffused mainly through the cell walls; hence, the moisture gradient in the thickness is sharper and the parabolic shape is reached as soon as the outer layers establish a condition of equilibrium with the environmental air. As to impermeable wood, its surface moisture reaches a condition of equilibrium with the air very shortly after the beginning of the drying process, whereas the greater part of the inner layers preserve their initial moisture content. In this phase, mechanical resistance is at a minimum, and high temperatures are dangerous.

Shrinkage starts when the cell walls of the peripheral layers reach the saturation moisture content; as this process begins, the layers are subjected to tensile stress; the latter is more readily observable in medium-permeability wood (1st critical point). At the same time, the speed of drying begins to slow down (II phase). The average moisture content of the wood at the first critical point is approximately 2/3 of the initial moisture content + 10% for permeable wood, and about 2/3-3/4 of the initial moisture content for wood with medium permeability.

This is the phase in which the checks appear; they extend from the surface of the wood toward the centre (mostly along the rays) and, if viewed sectionally, they appear to be wedge-shaped.

As a 21-24% average moisture content is reached, the drying process enters into its III phase, where:

(a) the tensile stress is inverted (stress applied at the centre); and

(b) the outer layers are, in all cases, in equilibrium with the final climate which, is normally very dry (2-5%).

The mechanical resistance of the wood increases during this phase. The drying process slows down because the diffusion of water occurs mainly through the cell walls.

During this phase, the surface checks close, and the wooden pieces stretch and grow wider at the centre.

Drying speed is directly proportional to permeability, temperature and air circulation speed (air losing its effectiveness in the

III phase), and inversely proportional to density, to the size of the pieces and to the relative humidity of the air.

The drying stage in which the moisture content drops from 45 to 25% is the one where wood is most vulnerable to the action of blueing fungi and of other wood-damaging organisms. The longer the wood moisture remains within this stage, the greater the danger.

In this connection, particular attention should be paid to the drying of biodegradable fresh wood which tends to be subject to fungal attack. This category includes the sapwood of all wood species and wood species characterized by an undifferentiated heartwood (such as beech), particularly the tropical kinds of "whitewood" (Ramin, Ilomba, Koto, Obeche, Aniegrè, etc.). To this one must add the problem posed by internal blackening.

Due to the catalyzing action of temperature when water or vapour are present, the ligneous species containing glucosides, polphenols and acids are subject to chemical reactions which can blacken the inside of the sawn logs. Temperatures approximating 35°C provide optimal conditions for the xylophagous organisms, while any rise in temperature above this value enhances the danger of internal blackening. The only safe method against fungal attack and biodegradation is (besides complete saturation) a chemical inhibiting treatment. This kind of mould should be dried by treating it at low temperatures and at low relative air humidity levels.

Here, too, each case should be considered separately, taking into account the savings afforded by kiln-drying, on the one hand, and the fact that, even when the seasoning process is not induced artificially, fungal attack may occur and temperatures leading to internal blackening may be reached on the other.

The tropical woods display some peculiar features and defects which extend the range of the problems connected with drying. In particular, this is true for the species of south-east Asia which are firstly less known and are secondly characterized by less foreseeable and more variable reactions. Tropical wood is represented, almost exclusively, by diffuse-porous hardwood; many of these species, however, contain resin and oleiferous canals, both in the wood and in the parenchymatic rays. The accumulation and hardening of these substances in the outer layers during drying form an exceptional barrier for the water which cannot flow freely to the surface. This phenomenon often results in collapse and in the formation of water pockets inside the wood. Generally, the differences in permeability are sharper, even within the same species, and so are the differences between the sapwood and the heartwood and, therefore, between different boards drawn from the same log.

Some wood species contain substances whose vapours emit a bad odour (Ramin and others) consequently air emitted from the drier during the drying process pollutes the environment. Some factories located in the proximity of built-up areas have had to install special plants for filtering the air emitted by the driers.

Many kinds of wood contain salts in varying quantities: the latter interfere with the electric measurement of the wood moisture content and often lead to variations from standard values, preventing the automatic devices from operating normally.

Woods characterized by interlocked grain, softness of its heartwood and by growth stresses pose particular problems.

As far as permeability is concerned, the following rough classification can be taken as a guideline:

-- <u>permeable wood</u>: all types of hardwood endowed with tracheids, generally speaking, those kinds of wood whose duramen (or heartwood) is undifferentiated, are most commonly classified among the diffuse-porous types of wood, e. g.,: beechwood, limewood, poplar-wood and the so-called tropical kinds of white wood, such as: Obechè, Abura, Jelutong, etc.; the sapwood of all kinds of hardwood;

-- medium-permeable wood: undifferentiated sap-wood and heartwood of conifers, due to the areolated pits;
-- impermeable wood: hardwood duramen with closed vessels due to tyloses, such as: oak, chestnut, many tropical and southern kinds of wood as well as the false heartwood of undifferentiated-duramen hardwood.

It follows that any wood-drying operation requires specific techniques or should, at least, be controlled in such a way as to:

-- increase the speed of the drying process;
-- avoid damage, such as: bioregression, splitting and checking of the wood, distortion, stresses, etc.;
-- obtain the desired final moisture content, i. e., the stabilization of shape and dimensions.

2. DRYING MEANS

2.1 Air and Combustible Gas

The main characteristics of air are: temperature, pressure, specific volume, volumetric weight, humidity and heat content (enthalpy), which are interdependent in accordance with well-known basic laws, from which it follows that:

-- the weight of air is proportional to its pressure;
-- steam tends to spread to where the pressure is lowest;
-- if the atmospheric pressure of the air-steam mixture is kept constant, a rise in temperature causes the dry air to expand and its pressure to drop, hence a rise in the pressure of the steam: one may

conclude that a rise in temperature enables the air to include larger quantities of steam.

The maximum pressure that steam can reach in the wet air is called "saturation pressure".

If the actual pressure of steam (P_v) for a given temperature is less than the saturation pressure (P_{vs}), the air is not saturated. The ratio between the above two quantities is called "relative moisture of air". It is usually expressed as a percentage, namely multiplying the ratio by 100. The moisture of air can be expressed with the ratio between the weight of the steam contained in the air and the weight of the steam in its saturation condition. If the relative air/moisture is less than 100%, it follows that the pressure of the steam contained in the air is less than the saturation pressure and, therefore, the air can absorb the steam from those areas where the pressure of the latter is highest. This process is known as "evaporation".

Exactly how much steam the air can contain depends on the temperature. The maximum steam content (saturation moisture) for some temperatures is shown in Table 4, which applies to a pressurized 760mm mercury column (1 atm = 1.033 Kg/m^2).

Table 4

Air Saturation Pressure and Moisture at Different Temperatures

Temperature in °C	Saturation Press in mm of Hg	Saturation Water in g/cu m	Absolute Saturation Humidity in g Per kg of Dry Air
10	9.2	9.4	7.6
20	17.5	17.3	14.7
30	31.8	30.4	27.2
40	55.3	51.1	48.8
50	92.5	82.1	86.2
60	149.4	130.1	152
70	233.7	198	276
80	355.1	293.9	545
90	505.8	423.1	1400
100	760	600	dry air is absent

The heat of wet air is equal to the sum of the heat contents of dry air and of the steam contained in it; thus, the heat content of air at a given temperature increases when the humidity increases.

In the drying process, air can fulfill a two-fold function: heating the material (Wood + Water) and discharging the water (evaporation); alternatively, it may fulfill only the latter function. In either case, the air undergoes variations in temperature and humidity that can be reversed through conditioning. In its narrowest sense, air conditioning consists of the following processes:

- a rise in temperature through heating, i. e., through the addition of heat;
- a fall in temperature through cooling, i. e., through the reduction of heat;
- an increase in relative humidity through moistening, i. e., the addition of steam;
- a drop in humidity through drying, i. e., through the removal of steam. This can be executed through a partial change of air or through the partial condensation of the steam contained in the air.

Combustible gas has similar characteristics to those of air; moreover, it can be mixed with air and steam for conditioning purposes.

2.2 Steam

The hygroscopic equilibrium of wood in saturated steam at standard atmospheric pressure is just a few per cent units below the saturation point of the cell walls.

Superheated steam is steam that has a higher temperature than the saturation one with respect to a given pressure. Saturated steam, e. g., with a temperature of 115°C, should have a pressure of 1.7239 Kg/cm^2, according to the steam content Table. Superheated steam is unsaturated (in our example, its relative humidity is $\frac{1.0332}{1.7239} = 0.6$), therefore it tends to bring about an evaporation process, namely, to absorb the steam and to heat - in short, it tends to release heat energy by cooling down even before its condensation. Because of its peculiar qualities, it can be employed for kiln-drying wood.

2.3 Vacuum

The distinctive feature of vacuum is that it lowers the boiling temperature of water, as shown by the data included in the following table:

Absolute Pressure p_o mm Hg	Boiling Temperature t_{eb} °C
760	100
355	80
150	60
55	40
18	20

Because of its peculiarity, vacuum has already been applied successfully in the medical and biological fields and in the food industry in order to dry highly sensitive, perishable materials. Similarly, efforts are being made to apply vacuum to the drying of those species of wood that are particularly sensitive to high temperatures.

Vacuum drying can be performed either through the evaporation of water or through the sublimation of ice; in the latter case, however, very high vacuum is required (p_o = 0.2...2 mm Hg), because the operating temperature is -30°C.

2.4 High-Frequency Electric Power

Since wood is a strong dielectric, high frequency current can be applied as a source of heat in the hygrothermal treatments of wood, using frequencies comprised between 2 and 40 MHz.

Internal heating tests have been started recently, with the use of microwaves which operate in a frequency range exceeding 900 MHz.

2.5 Infrared Rays

Infrared ray absorption is very high in wood (1...2 μ), but its permeability to these rays is almost irrelevant: they are not able to go any further than 4-5mm in depth. Wood hardly reflects the rays so it can be heated without energy losses. Due to the limited depth of penetration within the wood, the effect and development of the heating process is similar to the one experienced with the propagation of heat by convection or by contact.

2.6 Liquids

Among the various hydrophobe liquids (namely, liquids that do not mix with water), one uses those whose boiling temperature is higher than that of water: flax oil, coaltar oil, but above all the solid residues of petroleum distillation, which in Italy are usually referred to as paraffins and composed of paraffin, ceresine and high viscosity oils (basically, a yellow mass that fluidifies at a temperature of 50°C and boils at 250°C). These materials are not toxic: their volume weight is 0.9. Here the process takes the form of a bath treatment.

Azeotropic mixtures reach their boiling point at a lower temperature than that of their individual components. For example, mixtures containing water boil at temperatures below 100°C (the tetrachloroethylene-water mixture boils at a temperature of 87°C): this specific features is of great help for eliminating part of the water present in the wood because the mixture vapours condense and can, therefore, be separated.

Polar hydrophile organic solvents, which are soluble in water, are particularly suited to eliminate, together with the water, also the wood extractives. Acetone, alcohols, either can be employed for this purpose.

After their extraction, the solvents are redistilled (rectified).

2.7 Organic Solvent Vapours

In this case solvents that are not soluble in water must be used, for instance, xylol, toluol, tetrachloroethylene, or fractions of tar distillates having low boiling temperatures. The heat of vaporization of these solvents is less than that of water, the heat transmission coefficients are very high.

Organic solvent vapours are used for vacuum drying.

2.8 Saline Solutions

The pressure of the vapour in a saturated saline solution is lesser than that of steam. For this reason the water flows from the wood into the solution.

Salts or hygroscopic compounds such as: common salt, urea, treacle or invert sugar, polyethylene glycol are used in two - or even three-component solutions for other purposes besides wood drying, in particular in order to reduce the hygroscopicity of wood and improve its dimensional stability.

3. NATURAL SEASONING

The main purpose of seasoning is to reach the degree of humidity at which the wood is safe from deterioration caused by micro-organisms and insects (18-20%).

The minimum moisture content attainable through seasoning depends on micro-climatic and other local conditions and is likely to vary between 8 and 20% in our conditions: seasonal trends play a major role in this area. The humidity of seasoned wood left in the open air varies during the year according to climatic changes.

Sawn lumber is usually left to season in open yards which are selected on the basis of their drying factors and are arranged planimetrically in fields and sectors in which the wood piles are placed. Partition belts and haulage passages should be settled between the various sectors. The land should be consolidated, made thoroughly level, with a suitable inclination for draining the discharge waters, and cleared of any existing vegetation or other organic matter.

The size and number of the piles depends on the haulage system and on climatic conditions: the more ventilated and drier the area, the wider the stacks (1.2 - 4m); on the other hand, the distance between piles ranges from 0.75 to 2m. The direction of the boards should be established in each separate case, depending on the prevailing wind direction.

As soon as it is sawn, the lumber that is to be seasoned should be brushed and cut down to lath piles; lumber subject to deterioration and biodegradation, as well as any subsidiary material, should be treated with antiseptics: this applies especially to those kinds of wood that are more likely to be attacked by fungi. The lumber piles should always be covered and any high-quality material should be supplied with suitable protection at the cross-cut ends.

The stands of the piles are composed of concrete pillaring and crossties made of (treated) wood or reinforced concrete; thus, the first boards are roughly 30cm above ground level.

The piles should be covered with roofs of the weathered type so as to permit aeration and protect also the sides of the piles from rain and sunlight. Piles that are too exposed to the sunlight should be entirely protected along the sides by means of rejected boards, canes, etc. The planks in the horizontal rows are spaced out, and the damper the climate, the wider the space between one board and the next (a vertical empty space can possibly be formed at the centre of the stacks).

The piles may reach up to 7m in height, but they usually do not exceed 4.5 - 5m.

Each stack should include only wood belonging to the same species, and having the same thickness and initial moisture content.

The lumber can be stacked in other ways depending on one's specific requirements: "en boule" sawn lumber is stacked for following the original position occupied by each board in the log, the splined friezes are stacked together in piles up to 7m long and up to 1.5m wide, sometimes standing on edge in order to dry more quickly; if they are very short, semi-finished boards are arranged with a given distance between them; if they exceed 70cm in length, they are cut into laths.

High-quality lumber is seasoned in sheds (or under fixed protecting roofs) provided with adjustable openings in order to ensure good air circulation; lumber sheets require fixed shelvings.

Methods for enhancing the seasoning process: stand the boards upright (pre-seasoning of those kinds of wood that have a high moisture content and are likely to darken in colour: birch, maple, poplar); compression, centrifugation - possibly combined with the action of gravity - artificial ventilation, employment of solar energy. These methods, however, are applied only in special cases because they usually entail higher costs.

Bulk storage capacity for seasoning is highly variable, because it depends on a number of factors connected with stacking. On average, however, standard boards in 5m high piles require a capacity ranging from 0.5 to $1m^3/m^2$ of yard area.

4. KILN-DRYING

In practice, industry basically adopts three drying methods: (1) conventional drying, (2) condensation drying, and (3) vacuum drying.. Other drying methods, even though technologically advanced, such as the saturated steam methods, the high frequency method, etc., are applied only exceptionally. The "condensation" and "vacuum" drying methods - which are adopted at present -- were first introduced and developed in Italy; thus, they are of particular interest to us.

4.1 Conventional Drying

A so-called "classical (or conventional) drier" is one in which the air is recirculated artificially, heated through steam or hot water radiators, conditioned through a partial change of the air itself, and in which the wood is dried at a temperature included between 40 and 100°C. Air fulfills a twofold function: heating by convection and discharging the water (vaporization). If necessary, the air is humidified through the injection of steam or nebulized water.

From an economic point of view, drying by convection is the most profitable method, especially in order to save energy.

This drying method was developed through closet or conveyor ovens made of stone or sheet iron and fitted with machinery for recirculating and conditioning the drying means (air). Both the closets and the conveyors must be waterproof, corrosion-resistant and insulated in order to avoid losses of heat, condensation and unbalance in the air conditioning process.

There are considerable differences among the various types of construction, especially as far as the position of the fan is concerned: all types perform well as long as one makes sure that the air circulates uniformly through the stack.

Closet driers equipped with overhead fans are the most widespread ones in Central Europe, because here research tended to focus on the uniformity of the air circulation in this type of drier. Moreover, the method involving a partial change of the air contained in the drier has prevailed over the water cooling condensation method. In the field of automation, however, the system based on the continuous measurement of wood moisture is the prevailing one.

Where large quantities of timber are handled through fork (pallet) trucks, with pile systems, it is most rational to build large cells (or closets) into which the pile can be introduced directly, especially when the boards are of considerable size and density. The capacity of these cells may reach $500m^3$.

Artificial drying processes include:

-- a preliminary pre-heating treatment;
-- the actual drying process;
-- several treatments designed to improve the state of the material (the quality of drying) - i. e., after-treatments.

The initial conditions required in order to dry the material successfully are: uniformity of the wood characteristics (with reference to permeability and density), of thickness and of initial moisture content; all the boards should be derived from the same parts of the logs, and should be without bark and not subject to internal stresses; there should not be substantial differences in temperature among different parts of a single board.

The pre-heating treatment is to be effected simply with the initial drying climate, raising the temperature by 10-15°C. This treatment lasts as many hours as the centimetres of thickness of the wood.

Factors guiding the choice of the suitable conditions of treatment: thickness of the boards, volume weight of the wood, content of extractives and other substances (grease, oils), air circulation speed; the greater the value of these factors, the lower the temperature and the higher the relative humidity of the air; these conditions must be met if the treatment is to be effected successfully.

Modern wood technology has discovered that the drying process should be carried out:

-- with a constant "degree" of dryness, at least during the first two phases (the "degree of dryness" is the ratio between the humidity of the outer layers of the wood and the moisture content equilibrium of the wood with the drying air climate);
-- with a constant low temperature in the first two phases and raising the temperature in the third phase, and
-- keeping the relative humidity of the air constant in the first phase and reducing it progressively in the following phases.

Recommended drying treatment conditions for various kinds of wood and for 3 thickness groups are shown in Table 5. Instead of referring to the two temperatures, one can refer to their difference (psychrometric difference).

As it progresses, the drying process should be followed by weighing the control samples, which shall have the same initial moisture content displayed by the test pieces.

Where large closets are employed, the drying process should be managed automatically through the continuous electric measurement of the humidity present in the control boards.

The drying process can also be timed when certain kinds of wood are treated - namely, Norway spruce and Pine as well as tropical types of whitewood - and when the dry wood is not required to be of the best quality.

It is extremely difficult to state in advance how long a drying process should last, because of the considerable number and complexity of the factors involved.

Whatever the method followed for calculating process time, the latter should be considered merely as a rough estimate. Moreover, calculations may be useful in order to find out where the critical points are reached and to control the final stages of the drying process even though contact with the real process is lost.

In spite of the care with which the drying treatment has been carried out, at the end of the process boards often have different moisture contents, and a more or less sharp humidity gradient is found in the cross-sections of the pieces with ensuing stresses on the inner layer. This is why the material should undergo the equalizing and conditioning treatments.

Usually, only the humidity equalizing treatment is applied; the purpose of this treatment is to supply all the planks with a roughly equal humidity content. The final moisture content required for the wood is obtained through the employment of conditioned air while, simultaneously, raising the temperature.

The final conditioning treatment is designed to equalize the humidity contained in the boards by reducing the sharpness of the humidity gradient. In particular, this treatment is required for eliminating water pockets (silver fir, oak) and final stress. It is carried out through the employment of very hot and wet air (the percentage of humidity present in the climate should be 3-4 points higher than the average humidity present in the wood). This operation is more likely to be successful if performed towards the middle of the III phase rather than at the end. The treatment is also useful for sterilizing and eliminating moulds which may possibly appear in the course of drying.

Kiln-dried lumber should be stored in places where it is not subject to seasonal climatic changes. In particular, boards that are very thick and are to be subjected to further resawing and cutting, should be stored for some time after drying, as the elimination of stresses in the drier, which is absolutely necessary in these cases, entails high costs and is difficult to achieve. The stresses present in stored lumber lessen through time as the tissues undergo slow plastic deformations. If the humidity is not too low and the boards are stacked in contact with one another (12-14%), the material can be stored in adjustable-ventilation closed stores; if, on the other hand, the percentage of humidity is low (6-8%) and the lumber remains stacked when it leaves the drier, the store should be supplied with air-conditioning facilities. Stresses relaxation is best in stacks where the planks are in contact with one another.

4.2 Condensation Drier and Drying Method

Condensation driers and the condensation drying method were successfully introduced about 15 years ago; at the time, this method was publicized as a "stabilizing" treatment. The condensation drying technique is based on the same principles as the conventional partial air change technique. Here, too, the drying means is air, which circulates through the wood stack at normal atmospheric pressure, and causes the water to vaporize through the surface of the wood, as the convection (exchange) of heat takes place.

The drier is composed of a closet, in which the lumber laths are placed, and of a drying machine. The latter, in its turn, includes a heat pump, a recirculation fan and an additional heating set, the whole unit being enclosed by a sheet metal casing.

From a functional point of view, there are two different systems:

- one is based on a partial recirculation of the air through the drying machine;
- the other involves total recirculation of the air through the drying machine.

The following functional outline refers to the former case:

(1) the air penetrates into the wood stack in relatively dry conditions;

(2) the air that comes out of the stack has a

lower temperature and a higher degree of humidity;

(3) part of the air is sucked in and passes through the drying machine, while the rest continues to circulate in the closet; the air that passes through the machine is cooled until it reaches its dew point or an even lower temperature: this leads to the condensation of the humidity contained in the air; thus, the initial conditions (point 1) are restored;

(4) the air must be heated until it reaches, in the mixture, the initial conditions of point 1.

In total recirculation driers, the initial conditions are restored by heating all the air in the drying machine.

The system involving the total recirculation of air throughout the stack has several advantages, namely:

(a) all the various parts of the machine are included in a single casing, which can be connected to the closet without further assembling;

(b) all the controls are placed together;

(c) the climate can be adjusted more readily and more efficiently.

Also, higher drying temperatures and better air conditioning can be obtained without having to install additional equipment inside the closet. One disadvanrage, however, is that it is much more difficult to distribute the air evenly throughout the stack.

The machine can be fitted either inside the closet or outside it.

Condensation driers have developed considerably, since they were first invented. In their first stage, condensation driers were constructed with extremely low air circulation speeds, and their working temperatures did not exceed 35°C. Both the drier and the additional set were powered only through electric energy and there was no possibility of performing a total conditioning treatment. The drying process was very slow, and attainable moisture contents were in the region of 25-30% because the time and costs required for reaching a lower moisture content were too high: looking at the matter in retrospect, it was to be considered merely a pre-drying process.

These types of driers have recently been improved in order to obtain complete air conditioning (through the introduction of spray nozzles), and in order to operate at temperatures exceeding 50°C; the additional heating set can operate either with hot water or with steam (which may reduce operating costs considerably), while the air circulation speed can be programmed according to one's specific drying requirements.

Moreover, where multi-cell sets are employed, the heat emitted by the additional condenser can be recuperated and used for heating the other cells when operating alternatively. Thanks to these improvements, the functional conditions of condensation driers are now virtually similar to those of conventional driers. Thus, the condensation drying method is applied in almost all the relevant industries. Generally speaking, its best field of application is that of hardwoods and wherever electric power can be obtained at low cost. Recent designs suggest using the heat pump also for pre-heating, exploiting the heat of the outside air.

Heat pump condensation driers have proved exceptionally efficient energywise (total consumption is in the region of 0.5-1.5 kWh per kg of water).

Further development, especially with regard to temperature, is expected to take place in this field.

4.3 Vacuum Driers and Drying Method

The vacuum drying method was first applied 12 years ago with the introduction of the first plate-heating vacuum driers.

For a long time interest and research have focused on the drying process. Two main characteristics provided the starting point for further investigation, namely: that a pressure gradient leads to (1) an increase in the speed of wood moisture movement and (2) to a fall in the boiling temperature of water. Due to this set of circumstances, drying time becomes exceptionally short and the quality of drying is improved considerably, especially with regard to the even distribution of humidity in the wood.

The vacuum drying system which was first applied in Italy was based on the repetition of the following three-phase cycle: (1) contact heating by means of the hot water plates, (2) cooling of the surface of the lumber, and (3) vacuum-pumping up to 20-40mm Hg, condensation occurring in the circuit of the vacuum pump equipped with a condenser and, partly, on the lining of the autoclave.

Tests carried out in the course of several years have shown that, through contact heating, drying can be performed as an almost continuous process. The method now consists of two-phase cycles, namely: a vacuum-pumping phase, and a subsequent one during which this operation is stopped; the heating operation, instead, is carried on continuously.

In a recent design, the vacuum is continuous and the steam condenses in the cylinder placed above the water cooling set.

A further contribution to the development of this system has been made through the introduction of convection heating with conditioned air circulated artificially. The wall of the autoclave acts as an air-heating unit, which is heated by the hot water (or steam) that is introduced through the interspace formed by another external cylinder. The Air is moistened through steam spraying. The cycles are two-phased: (1) heating by means of air that is recirculated through side fans, and (2) vacuum pumping, during which vaporization occurs. Steam mixes in the pump with the relevant liquid, is condensated in a heat exchanger, finally, the condensate is separated from the liquid. Through the heat exchanger, the manufacturer has also found a suitable way of recuperating condensation heat, because it can be used to heat the water contained in the heating circuit. It has been found out that, in an alternating two-cylinder set, the heat obtained through recuperating is sufficient for heating the wood; therefore, once the first heating operation is carried out, the boiler can be cut out from the heating circuit of the drier.

An efficient insulation is of material importance for this new type of drier.

Another highly relevant feature of this new system relates to the possibility of performing the heating operation with temperatures exceeding 100°C because the steam-liquid mixture of the pump reaches temperatures in the region of 140°C.

The new convection-heating vacuum-drying system ensures high-quality drying, that can be noted, primarily, in the absence of a humidity gradient in untylosed[2/] hard lumber (even when the boards are large), at the end of the drying process; another advantage, however, is its ability to carry out final treatments, hence improve the state of those types of wood whose vessels are obstructed by tyloses. The material can be heated with conditioned air. The haulage, loading and unloading operations are simplified and plate maintenance costs are eliminated. Total drying time is reduced, although the heating phases last somewhat longer. The versatility

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[2/] (i. e., whose vessels are completely clear of any obstruction due to tylosis) of the vacuum-drying system is, thus, increased considerably and is now in a position to deal with almost all the possible situations.

Also its radiant efficiency is exceptionally high, due to the recuperation of heat through the connection of the heat exchanger, and it can be almost total, as in the heat pump.

5. AUTOMATION OF THE DRYING PROCESS

Recent efforts, both in the experimental and in the productive fields, to automate kiln-drying are based on one of three methods used for recording variations in the state of the material while it is in the cells: (1) weighing the whole stack of lumber with the application of so-called "load cells", (2) measuring pile shrinkage, and (3) continuously measuring the moisture content of the wood and of the climate through electric resistance (conductance).

The latter is the one usually adopted in industrial practice because it is the most flexible, if not the most accurate. An electronic computer controls the drive units in accordance with stored or periodically modified drying programmes. The development of this system has paralleled the development of electronic computer systems, with a gradual reduction in system rigidity resulting in losses of time and energy. Today the problem of rigidity and uncertainty concerning the measurement of the wood moisture content above the saturation point of the cell walls is dealt with micro-processors. A terminal video system has been introduced recently: besides enabling the storage of the desired programme, it is capable of supplying multiple information-processing.

However, there are two fundamental drawbacks to the automation of the drying operation: firstly, the field of measurement is limited by the point of saturation of the cell walls; and secondly, measurement itself is unreliable where salts are present. Micro-processing techniques are being used to cope with these problems; however, they should be taken into account. Problems with automation have been observed also in the "conventional" types of driers:

- Automation often slows down the pre-heating phase, especially if there is not enough steam available for moistening the air.
- The conditions underlying the "conditioning" treatment, as performed by presently existing automated systems, have no clear technological foundation. In fact, this operation is something between an equalizing and a conditioning treatment and, what is worse, it is timed.
- Probes often show inaccurate values for average wood moisture and exceedingly high ones for salt-containing tropical types of wood; hence, drying time is increased.
- The printed electronic cards are subject to wear and the instruments often deviate from their original calibration.

In any case, automation does not replace man and cannot manage these processes without his intervention, but it has proved very helpful and has greatly increased operational safety, particularly where the climate must be kept constant. The determination of initial and final moisture content - for large and dense lumber piles - tensile tests, and the determination of the humidity gradient in the wood are still the basic conditions for ensuring high functional quality. Automatic apparatuses must constantly be checked and calibrated, and control boards must be used in order to make sure the desired results are obtained. Hence, the reservations expressed by Italian manufacturers with regard to total automation, are justified. The industries producing driers and automatic equipment should be more responsible when advertising their products; statements to the effect that driers do not require the operations of qualified personnel if they are equipped with automatic apparatuses, cannot be accepted.

6. PROBLEMS CONNECTED WITH THE CHOICE OF THE DRIER

There is no general rule for choosing one drier rather than another; the actual conditions of each drier must be appraised carefully, especially from the point of view of saving and of capacity. Above all, one should consider the ratio between the costs of mechanical energy and heat energy.

I shall give hereunder some advice based on my own experience which, however, applies to specific conditions, namely: the low cost of heat energy obtained through recuperation of waste and, on the other hand, the high cost of electric energy; in Italy these ratio vary between 1:5 and 1:20 (Table 6).

Table 6 Comparative Table of the Three Main Lumber Drying Systems with the Relative Scores

1 Point - Lowest Score
3 Points - Highest Score

This table applies to the following standard products:

I - "CLASSICAL" drier
II - "CONDENSATION" drier
III - "VACUUM" drier

		System	
Characteristic	I	II	III
INVESTMENT	2	3	1
ASSEMBLY	1	3	2
MAINTENANCE	2	3	1
UNIVERSALITY	3	2	2
CAPACITIVE FLEXIBILITY	3	3	1
Rating by kinds of Wood:			
- HARDWOOD WITH VESSELS OBSTRUCTED BY TYLOSES	1	3	2
- HARDWOOD WITH VESSELS THAT ARE NOT OBSTRUCTED BY TYLOSES, HARD	1	2	3
- HARDWOOD WITH VESSELS THAT ARE NOT OBSTRUCTED BY TYLOSES, SOFT	2	1	3
- CONIFERS	3	1	1
SPEED DRYING	2	1	3
QUALITY OF DRYING	2	1	3
DISCHARGE OF OILS, RESINS	2	3	1
CHROMATIC ALTERATIONS	1	3	2
STERILIZATION, MOULDS	2	1	3
EQUALIZING	3	2	3
CONDITIONING	3	1	3

As far as cost is concerned, capacity being equal for all, the condensation drier is in first position, followed by the classical type of drier and by the vacuum drier, which is the dearest; in order to establish their productive capacity, simply reverse this order.

As to the costs entailed by drying all types of permeable wood (i. e., with vessels that are not obstructed by tyloses), the vacuum drier is certainly the most advantageous, while the condensation drier is best for low-permeability hardwoods, and the classical drier for softwoods (Conifers and light hardwoods).

Condensation or classical driers are best where considerable drying capacity is required.

As to drying speed, vacuum driers are the fastest; the classical and condensation ones follow in this order. However, condensation driers perform just as well as the classical ones where low-permeability wood drying is concerned, since in both cases relatively low temperatures must be applied.

As far as the quality of drying is concerned, vacuum driers seem to perform best; condensation and classical driers attain theoretically equal performance levels; condensation driers ensure better conduction for hardwoods because they operate with relatively low temperatures.

Considering the extremely great variety of the kinds of wood that must be dried, classical driers prove to be the most adaptable (i. e., the most universal) ones; vacuum driers are second and condensation driers are third best.

Condensation driers are the simplest to install: standard versions do not even require the installation of a boiler; vacuum driers follow, while classical driers are last in this order. In their standard versions, these last two require a boiler.

Climate adjustment is more accurate for total-conditioning condensation driers, especially during the summer, when the temperature and the humidity of the surrounding air are rather high.

Vacuum driers are the best for extracting and bringing oils and resins to the surface; classical driers are second best and condensation ones are the least effective. Vacuum driers are the best for sterilizing the wood and protecting it against moulds, while the reverse is true for condensation driers. From the ecological point of view (namely, with reference to the pollution of the environment), condensation driers are first, classical driers are last.

Condensation driers require less maintenance and repairs than the other two types of driers.

The first step in the design of a drying system should be that of calculating the capacity and the economic costs as a function of the actual production planned (quantity, ratio between species and assortments, initial and final moisture content of the wood, required quality of drying) for different drying systems and drying methods. A rational choice is always based on the adoption of a single drying system. The size of the closets should be a function of the daily capacity of the production cycle, of the transport system, of the size of the wood and of the stack. Rule out any plan that may require a change in the direction of the piles or downright restacking.

Where large volumes of wood - especially in hardwoods - must be dried, fit a small additional drier, operating with the same system as the main one, in order to carry out preliminary tests on the most suitable conditions of treatment.

The data (prices, time values, energy consumption) supplied by manufacturers and research institutes can be used for the economic and capacity calculations. Rough data concerning drying time and made available by drier manufacturers are shown in Tables 7 and 8 hereunder.

Table 7

Rough Estimate (in drying hours) of the time required for attaining a 10% final moisture content ("vacuum" drier)

Initial moisture content of the wood	80%				40%			
Thickness mm	30	50	70	90	30	50	70	90
Species	Time h				Time % h			
Quercus robur, chestnut, red lauan and other impermeable kinds of wood	230	350	-	-	120	170	210	240
Beech, walnut, hornbeam, cherry, sipo, African mahogany	110	138	182	218	57	75	104	130
Ash, maple, afrormosia, beté, white lauan	46	122	158	194	48	70	96	122
Douglas Fir, Pines larch, obeche	67	82	108	132	37	53	73	92

NB: Pre-heating time is not included

Table 8

Rough Estimate of Condensation Drying Time During Peak Production Periods

Wood moisture content (as a %)		80%				40%			
	initial	80%				40%			
	final	12%				12%			
Thickness mm		30	50	70	100	30	50	70	100
Fir, cedar, Swiss pine, Douglas cypress, larch, pine, pitch-pine, birch, hornbeam, mulberry, ilex; French elm (Ulmus campestris), alder, poplar, willow, linden, jelutorg, light-red meranti, sepetir, seraya, torentong		8-10	12-15	16-18	21-23	4- 5	7- 9	12-14	14-16
Fromager, balsa wood, dibétou, obèche (Samba, Ayous)		8-10	12-15	18-20	21-29	4- 5	7- 9	12-14	14-16
Chestnut, cherry, beech, ash, apple, walnut, wych-elm (Ulmus montana), dark-red meranti, mengkulang, kauri kempas, keruing, Ramin, teak, nyatoh, kalam, abura, bossé, aiélé ; framire, limbá, sipo, niangon, padouk, mecrusse, tiama, mahogany, sapelli, beté		10-12	13-16	20-22	23-25	6- 7	8-11	14-16	16-18
Maple, Turkey oak, eucalyptus, locust, English oak, pear, olive, balau, lauan, kéranj, meravan, ebony, bété, iroko, mugwort peu, rosewood, ramin, sandalwood, afrormosia, teak, aningré, doussié		12-13	15-18	22-25	26-28	8- 9	10-12	16-18	18-20