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TRAINING IN WOOD DRYING AND KILN MAINTENANCE

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THE COMMONWEALTH OF DOMINICA

Technical report: A simple guide to timber drying*

Prepared for the Commonwealth of Dominica
by the United Nations Industrial Development Organization,
acting as executing agency for the United Nations Development Programme

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PREFACE

This small Guide to timber drying is based on experience gained in running a timber-drying Course in Dominica under the auspices of the United Nations Industrial Development Organisation and on previous wood drying experience.

Its aim is to explain in simple terms why wood needs to be dried, how it can be dried and ways of making sure that it is properly dried.

Lack of adequate wood drying or bad wood drying practice have resulted in misuse of wood and in the production of inferior wood products all over the world; the inability of many tropical countries to produce finished wood products which can be sold for export to sophisticated markets can very often be attributed to lack of good timber drying. This can deny them some very lucrative outlets for their timber and the chance to earn large quantities of foreign exchange with relatively small quantities of wood.

The hope is that this Guide will prove useful to those engaged in drying wood and those who use it and want to know whether they are getting a good product.

ACKNOWLEDGEMENTS

The writer is indebted to the United Nations Industrial Development Organisation for facilities to write this guide during the running of a timber drying course in Dominica. He is grateful to the Building Research Establishment, Princes Risborough, England and to FORINTEK in Canada, for permission to use tables and figures from their publications which are acknowledged in the text.

He is also grateful to the Government of Dominica for much assistance during the running of the course and to the Oxford Forestry Institute for facilities to produce the Guide, in particular Mrs. Cynthia Bunday, for hours of tedious work in preparing the text.

TABLE OF CONTENTS

Annex 1

Appendix 1

Tables

Figures

Introduction

The fact that wood shrinks when it dries and swells when it gets wet is well known but this property alone creates as many problems in the use of wood as any other factor.

Joints that come loose, cracks or warping in table tops, doors and drawers that don't fit, bowls that become oval and carvings that distort or split show some of the numerous faults that can result from poor or inadequate drying of the wood from which the articles are made.

Although wood is a varied and complex material the physical laws which govern the properties of wood and water and their interaction with each other, are basically quite simple and easy to understand. An understanding of them is, however, essential for anyone involved in drying timber or in using it to make a product accurately which has to remain stable after manufacture. Furniture and joinery, in particular, come into this category of product.

The aim of this guide is to show how wood and water behave and interact with each other and how the drying process can be monitored and controlled to give a product that is stable in use. It is hoped that an understanding of wood and how water affects it will lead to the production of quality wood products.

The Properties of Water

Water is a common but very remarkable material which is responsible for the world's climate being as equable as it is. It has the ability to hold and store large quantities of heat.

Water is found either as a liquid or a vapour (gas). In order to turn the water from a liquid into a gas a large amount of heat is required to increase the rate of movement of the molecules of liquid to the point where they are moving fast enough to escape from the liquid surface and become a vapour. About 5 times as much heat is required to evaporate one gram of water as is required to heat a gram of water from freezing point to boiling point. This is why a kettle of water on a stove will boil for a long time before it boils dry; it also explains why as people sweat the skin is cooled by taking heat from it to evaporate the sweat. The heat required is known as the "LATENT HEAT OF EVAPORATION" or "latent heat of vapourisation." When water condenses from a vapour to a liquid the same amount of heat is released.

As water is heated between freezing and boiling point an increasing amount of water is evaporated and the vapour produced exerts a pressure, the "VAPOUR PRESSURE". The vapour pressure very nearly doubles for every 10° Centigrade (Celsius) increase in temperature until at boiling point it is equal to the atmospheric pressure. The "SATURATED VAPOUR" pressure is the pressure exerted by the air saturated with water vapour at that temperature; air is saturated at a particular temperature when it can hold no more water vapour.

For every ten degrees increase in temperature, therefore, the capacity of the air to hold water vapour is almost doubled.

The "RELATIVE HUMIDITY" (RH) of air is the same as the "percentage saturation" of the air at that temperature or the water vapour contained in the air expressed as a percentage of the maximum amount of water vapour which the air could hold at that temperature. R.H. is a concept which is widely used in wood drying. It is called Relative Humidity because it only expresses the water as a percentage of saturation at that temperature; it is a measure of the "drying power" of the air.

If a volume of air at 100% R.H. (Saturation point) is raised in temperature by 10°C the R.H. will almost be halved to 50% if no water is added to the air or removed from it. If a volume of air at 80% R.H. is cooled by 10°C the R.H. cannot increase to over 100% and some vapour will condense as liquid water.

The property of water to remove heat from its surroundings when it evaporates is used in the "WET AND DRY BULB THERMOMETER". It has two thermometer bulbs, one of which is dry and the second of which is kept moist by a wick surrounding the bulb and dipping into water. The wick draws the water up around the bulb. The air passing over the wick evaporates water which cools the bulb and reduces its temperature and the temperature reduction is determined by the R.H. of the air. If R.H. is high, evaporation is small and wet bulb temperature "depression" is small. If R.H. is low the evaporation will be rapid and the depression greater. It is then possible to read off R.H. from tables giving the dry bulb temperature and the depression of the wet bulb (the number of degrees that the wet bulb is lower in temperature than the dry). Table I is such a table.

Table 1. Relative humidity-equilibrium moisture content table and saturated vapor pressure for use with dry-bulb temperature and wet-bulb depression —°C

Difference between wet- and dry-bulb temperatures in degrees Celsius

Temp. dry bulb (°C)	V.P. kPa	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0	22.0	24.0	26.0	28.0	30.0
0	0.6	91 20.5	82 17.0	73 14.3	64 12.2	55 10.5	47 8.8	39 7.6	31 6.3	22 4.9	14 3.5																				
5	0.9	93 21.6	86 19.4	79 15.9	72 14.0	65 12.3	58 10.9	51 9.7	45 8.5	38 7.5	32 6.5	19 4.4	6 1.9																		
10	1.2	94 22.4	88 19.5	82 17.2	76 15.3	71 13.7	65 12.4	60 11.2	54 10.2	49 9.3	44 8.4	33 6.8	23 5.2	14 3.5	4 1.3																
15	1.7	95 23.0	90 20.3	85 18.1	80 16.3	75 14.8	70 13.6	66 12.4	61 11.5	57 10.6	52 9.8	44 8.3	35 7.0	27 5.8	19 4.5	12 3.0	4 1.3														
20	2.3	96 23.4	91 20.9	87 18.8	83 17.1	78 15.7	74 14.4	70 13.4	66 12.4	62 11.5	58 10.6	51 9.4	44 8.2	37 7.2	30 6.2	24 5.2	17 4.1	11 2.9	5 1.6												
25	3.2	96 23.6	92 21.2	88 19.3	84 17.7	81 16.3	77 15.1	74 14.0	70 13.1	67 12.3	63 11.5	57 10.2	50 9.1	44 8.1	38 7.2	33 6.4	27 5.6	22 4.8	16 3.9	11 3.0	7 1.9										
30	4.2	96 23.7	93 21.5	89 19.6	86 18.0	83 16.7	79 15.5	76 14.5	73 13.6	70 12.8	67 12.1	61 10.8	55 9.7	50 8.8	44 8.0	39 7.2	34 6.5	29 5.8	25 5.2	19 4.5	15 3.6	12 3.0	8 2.2	4 1.3							
35	5.6	97 23.7	93 21.5	90 19.8	87 18.2	84 16.9	81 15.8	78 14.8	75 13.9	72 13.1	69 12.5	64 11.2	58 10.2	54 9.3	49 8.5	44 7.8	40 7.1	35 6.5	31 5.9	27 5.4	23 4.8	20 4.3	16 3.7	13 3.1	9 2.4	6 1.7					
40	7.4	97 23.6	94 21.5	91 19.8	88 18.3	85 17.1	82 16.0	80 15.0	77 14.1	74 13.4	72 12.7	67 11.5	62 10.5	57 9.6	53 8.8	48 8.1	44 7.5	40 7.0	36 6.4	33 5.9	29 5.5	26 5.0	22 4.5	19 4.1	16 3.6	13 3.1	8 2.0	2 0.7			
45	9.6	97 23.4	94 21.4	91 19.7	89 18.3	86 17.1	83 16.0	81 15.1	78 14.2	76 13.5	73 12.8	69 11.6	64 10.6	60 9.8	56 9.0	52 8.4	48 7.8	44 7.3	40 6.8	37 6.3	34 5.8	30 5.5	27 5.1	24 4.7	22 4.3	19 3.9	14 3.1	9 2.2	4 1.2		
50	12.3	97 23.1	95 21.2	92 19.6	89 18.2	87 17.0	84 16.0	82 15.0	80 14.2	77 13.5	75 12.8	71 11.7	66 10.7	62 9.9	58 9.2	54 8.5	51 8.0	47 7.5	44 7.0	40 6.5	37 6.1	34 5.8	31 5.4	28 5.0	26 4.7	23 4.4	18 3.7	14 3.0	10 2.3	6 1.5	2 0.6
55	15.8	97 22.8	95 20.9	92 19.4	90 18.0	88 16.9	85 15.9	83 15.0	81 14.2	79 13.4	76 12.8	72 11.7	68 10.7	64 9.9	60 9.2	57 8.6	53 8.0	50 7.5	47 7.1	43 6.7	40 6.3	38 5.9	35 5.6	32 5.3	30 5.0	27 4.7	22 4.1	18 3.5	14 2.9	10 2.3	7 1.7
60	19.9	98 22.4	95 20.6	93 19.1	90 17.8	88 16.7	86 15.7	84 14.8	82 14.0	79 13.3	77 12.7	73 11.6	69 10.7	66 9.9	62 9.2	59 8.6	56 8.1	52 7.6	49 7.0	46 6.7	43 6.4	40 6.0	38 5.7	35 5.4	33 5.1	30 4.8	26 4.3	22 3.8	18 3.3	14 2.8	11 2.3
65	25.0	98 22.0	95 20.3	93 18.8	91 17.5	89 16.4	87 15.5	84 14.6	82 13.9	80 13.2	78 12.6	74 11.5	71 10.6	67 9.8	64 9.1	60 8.5	57 8.0	54 7.6	51 7.1	48 6.8	45 6.4	43 6.1	40 5.8	38 5.5	35 5.2	33 4.9	29 4.4	25 4.0	21 3.5	17 3.1	14 2.7
70	31.2	98 21.6	96 19.9	93 18.5	91 17.2	89 16.2	87 15.2	85 14.4	83 13.6	81 13.0	79 12.4	75 11.3	72 10.4	68 9.7	65 9.0	62 8.5	59 8.0	56 7.5	53 7.1	50 6.7	47 6.4	45 6.1	42 5.8	40 5.5	37 5.2	35 5.0	31 4.5	27 4.1	23 3.7	20 3.3	17 2.9
75	38.6	98 21.1	96 19.5	94 18.1	92 16.9	90 15.9	88 15.0	86 14.1	84 13.4	82 12.8	80 12.2	76 11.1	73 10.3	70 9.5	66 8.9	63 8.4	60 7.9	57 7.4	54 7.0	52 6.6	49 6.3	47 6.0	44 5.7	42 5.5	39 5.2	37 5.0	33 4.5	29 4.1	26 3.8	23 3.4	19 3.1
80	47.4	98 20.6	96 19.1	94 17.7	92 16.6	90 15.5	88 14.7	86 13.9	84 13.2	82 12.5	80 11.9	77 10.9	74 10.1	71 9.4	67 8.8	64 8.2	61 7.7	58 7.3	56 6.9	53 6.6	51 6.2	48 5.9	46 5.7	44 5.4	41 5.2	39 4.9	35 4.5	31 4.1	28 3.8	25 3.5	22 3.1
85	57.8	98 20.1	96 18.6	94 17.3	92 16.2	90 15.2	88 14.3	87 13.6	85 12.9	83 12.3	81 11.7	78 10.7	75 9.9	72 9.2	69 8.6	66 8.1	63 7.6	60 7.2	57 6.8	55 6.4	52 6.1	50 5.8	47 5.6	45 5.3	43 5.1	41 4.9	37 4.5	33 4.1	30 3.8	27 3.5	24 3.2
90	70.1	98 19.6	96 18.1	94 16.9	92 15.8	91 14.8	89 14.0	87 13.3	85 12.6	84 12.0	82 11.4	79 10.5	76 9.7	73 9.0	70 8.4	67 7.9	64 7.4	61 7.0	59 6.7	56 6.3	54 6.0	51 5.7	49 5.5	47 5.2	45 5.0	43 4.8	39 4.4	35 4.1	32 3.7	29 3.4	26 3.2
95	84.5	98 19.1	96 17.7	94 16.4	93 15.4	91 14.5	89 13.7	88 12.9	86 12.3	84 11.7	83 11.2	79 10.3	76 9.5	73 8.8	70 8.2	68 7.7	65 7.3	62 6.9	60 6.5	57 6.2	55 5.9	53 5.6	50 5.4	48 5.1	46 4.9	44 4.7	40 4.3	37 4.0	33 3.7	30 3.4	27 3.1
100	101.3	98 18.5	96 17.2	95 16.0	93 15.0	91 14.1	90 13.3	88 12.6	86 12.0	85 11.4	83 10.9	80 10.0	77 9.2	74 8.6	71 8.0	69 7.5	66 7.1	63 6.7	61 6.3	58 6.0	56 5.7	54 5.5	52 5.2	49 5.0	47 4.8	45 4.6	42 4.3	38 3.9	35 3.6	32 3.3	29 3.1
105	120.8	98 18.0	97 16.7	95 15.5	93 14.6	92 13.7	90 12.9	88 12.3	87 11.7	85 11.1	84 10.6	81 9.7	78 9.0	75 8.4	72 7.8	69 7.3	67 6.9	64 6.5	62 6.2	60 5.9	57 5.6	55 5.3	53 5.1	51 4.9	49 4.7	47 4.5	43 4.1	39 3.8	36 3.5	33 3.3	30 3.0
110	143.2	98 17.4	97 16.2	95 15.1	93 14.1	92 13.3	90 12.6	89 11.9	87 11.3	86 10.8	84 10.3	81 9.5	79 8.7	76 8.1	73 7.6	70 7.1	68 6.7	65 6.3	63 6.0	61 5.7	58 5.4	56 5.2	54 4.9	52 4.7	50 4.5	48 4.3	44 4.0	41 3.7	38 3.4	34 3.2	32 3.0
115	169.0	98 16.9	97 15.6	96 14.6	94 13.7	92 12.9	91 12.2	89 11.6	87 11.0	86 10.5	85 10.0	82 9.2	79 8.6	76 7.9	74 7.4	71 6.9	69 6.5	66 6.2	64 5.8	62 5.5	59 5.3	57 5.0	55 4.8	53 4.6	51 4.4	49 4.2	46 3.9	42 3.6	39 3.3	36 3.1	33 2.9

Calculated from Hailwood-Horrobin single hydrate equation using parameters determined by Simpson (1973).

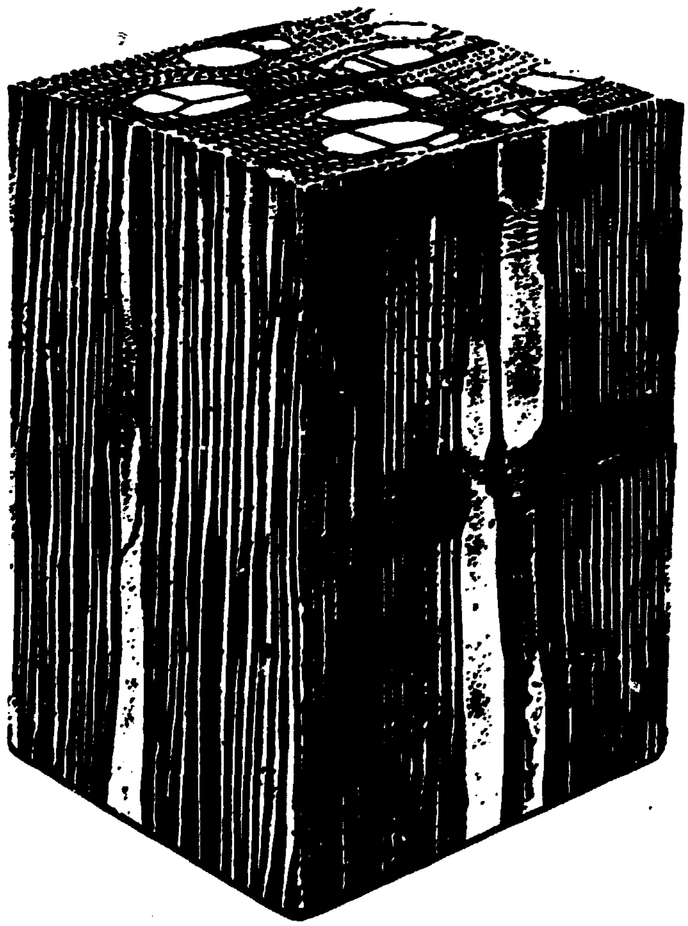
From: "Kiln drying of Western Canadian Lumber" by G. Bramhall & R.W. Wellwood, FORINTEK Canada Corporation.

Properties of Wood

Wood is made up of large numbers of "cells", only the largest of which are visible to the naked eye. Figure 1 shows a three dimensional view of a hardwood (wood of a broadleaved tree) and shows vessels, the main water conducting cells , fibres, the main structural cells and rays running radially with short radially aligned cells in bundles. There are other types of cell but these are the major ones.

The cells have central cavities called "lumens", filled either with water or air, and are separated from each other by "walls" made up mainly of "cellulose" and "lignin". There are passages or gaps in the cell walls from cell to cell called "pits" which vary greatly in size, shape and number. The cellulose is made up of long molecules aligned mainly along the length of the cells while lignin is not aligned in any particular direction.

FIGURE 1. Three dimensional view of Hardwood magnified to show Cell Structure.



<u>Properties of Water in Wood</u>

Water exists in wood either as liquid or as vapour in the cell lumens or as "bound water" in the cell walls. In the latter it is loosely attached to the cellulose molecules but can move from one molecule to another through the wall.

The term "FIBRE SATURATION POINT" is applied to wood when the walls of the cells are saturated but there is no liquid water left in the cell lumens. Below this point water is removed from the bound water in the cell walls and this causes the wood to start shrinking.

"PERCENTAGE MOISTURE CONTENT" is a term commonly used in wood drying and is:

$$\frac{\text{weight of the water}}{\text{weight of dry wood}} \times 100$$

It can be determined accurately by weighing a piece of wood, oven drying it at just over 100°C. until there is no more water left in it and weighing it again, then:

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

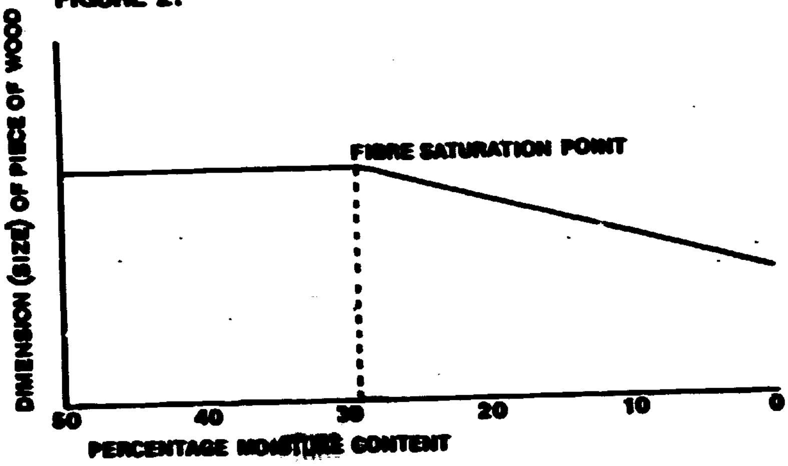
It is a percentage of weight not volume and, therefore, in dense, heavy woods green moisture content is less than in soft, light woods where there is a greater proportion of cell lumen to cell wall.

Below fibre saturation point the moisture content percentage is a good measure of the degree of saturation of the cell walls or the weight of water per gram of cell wall material, but there is more water in a given <u>volume</u> of dense wood at a certain percentage moisture content than there is in a low density wood at the same percentage mc.

Fibre saturation point for most timbers is at about 28 - 30% m.c. and below this the wood shrinks as m.c. decreases down to 0% m.c. and shrinkage is approximately proportional to the drop in m.c.

Fig. 2 below shows this in graphical form:

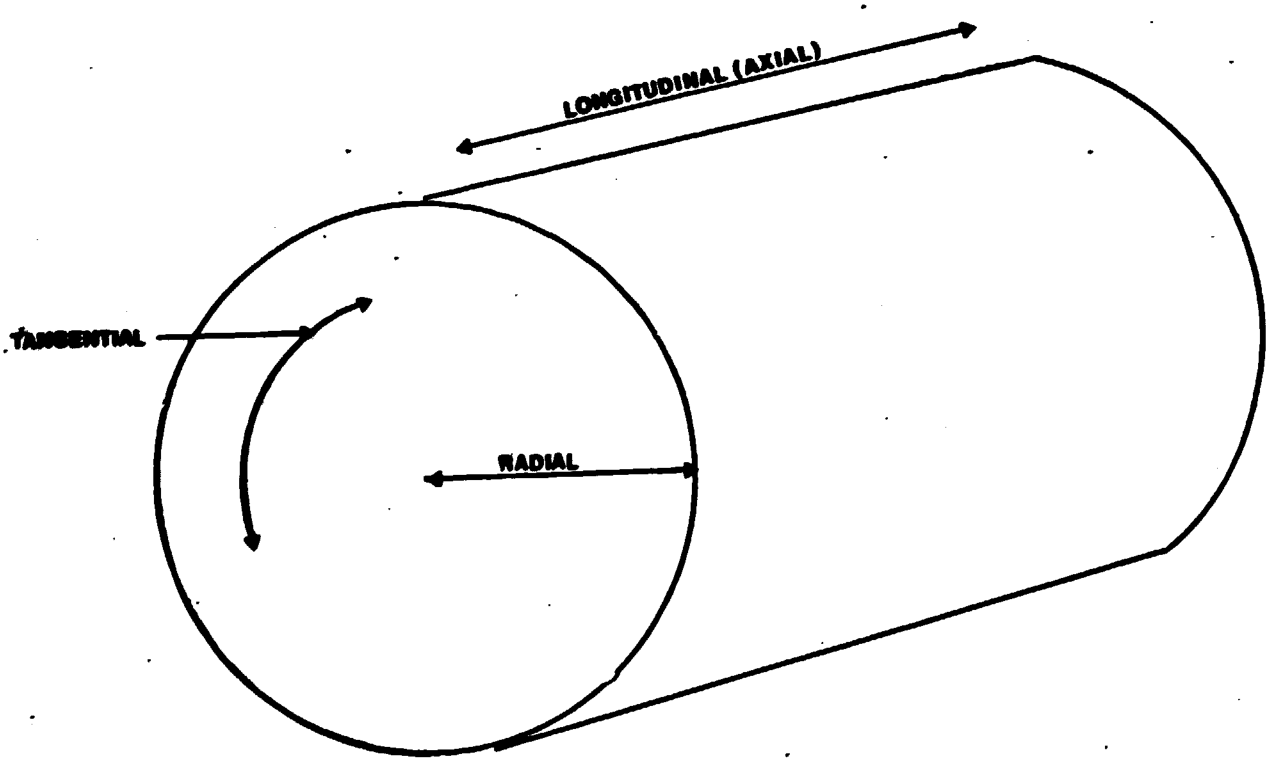
FIGURE 2.



Shrinkage, however, is not the same in different directions in wood because of the way wood is made up.

Figure 3. below shows the three directions or "planes" of shrinkage in a tree.

Figure 3. The Three Directions of Shrinkage in Wood.

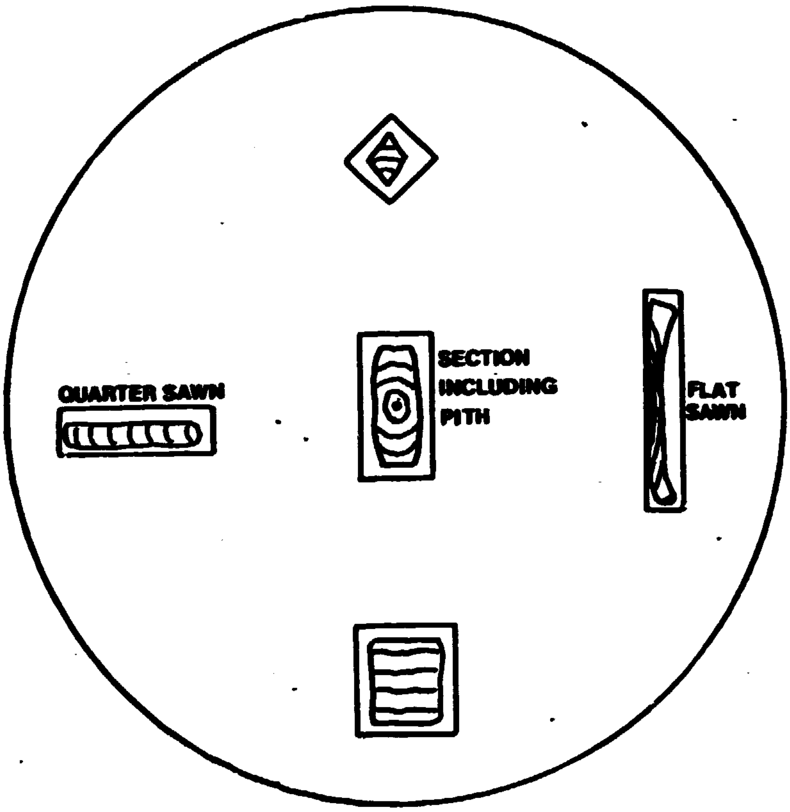


There is very little shrinkage along the length of the cells of the wood and, therefore, "longitudinal" or "axial" shrinkage is very low.

Radial is higher (normally about twenty times as great) and Tangential is greater still, normally one and a half to two times radial. The difference between radial and tangential shrinkage is often a cause of problems in the drying and use of wood.

Fig. 4. illustrates in an exaggerated way how wood cut in different ways from a log shrinks because of differences between tangential and radial shrinkage.

FIGURE 4. PATTERN OF SHRINKAGE IN TIMBER CUT IN DIFFERENT WAYS FROM A LOG CROSS SECTION



Note: Because tangential shrinkage is greater than radial shrinkage, the effect on timber shape after drying is important and is shown above in an exaggerated form.

The amount of shrinkage on drying varies between different species of tree because of the way in which the wood is formed and the different amounts of different types of cell. The lower the shrinkage is the more stable is the wood to changes in moisture content and the better it is for making articles where stability is important, such as furniture and joinery.

Table 2. below shows for typical high, medium and low shrinkage woods their percentage shrinkage from Green (fibre saturation point) to 12% m.c. The shrinkage is also given in terms of the shrinkage in width of a 12 inch (30 cm) wide board.

TABLE 2. Shrinkage between Green and 12% m.c. for High, Medium and Low shrinkage Wood.

Species of Tree	Tangential Shrinkage %	Tangential Shrinkage in 12" (30 cm) board	Radial Shrinkage %	Radial Shrinkage in 12" (30 cm)
Beech (High) *Fagus Sylvatica*	9.5	1 1/8" or 28.6 mm.	4.5	9/16" or 14.3 mm.
African Mahogany (Medium) (*Khaya anthotheca*)	4.5	9/16" or 14.3 mm.	2.5	5/16" or 7.9 mm.
Iroko (Low) (*Chlorophora excelsa*)	2.0	1/4" or 6.4 m.m.	1.5	3/16" or 4.8 mm.

EQUILIBRIUM MOISTURE CONTENT (EMC) is the moisture content reached when timber is left for a long time in certain conditions of temperature and humidity, (the moisture content at which it stabilises or reaches "equilibrium"); emc varies slightly for different species of wood but is fairly constant and table 1 and Fig. 5 give approximate emcs for different conditions of temperature and humidity. It is, therefore, possible by monitoring temperature and humidity over a period in a particular location to get an idea of the emc that wood in those conditions will reach. The aim of timber drying should be to dry timber to the emc which prevails in the location where it is going to be used. If this is achieved no shrinkage or swelling will occur, but in practice climatic variations throughout the year and other factors, make it inevitable that some changes in temperature and humidity will affect the moisture content of the wood but they should be small and the wood is slow to lose or pick up moisture so daily variations will be negligible.

The difference in emc of air dried timber and timber inside a building with windows and doors is considerable partly because air dried wood picks up water at night when humidities are high whereas wood inside the building does not do so. In most humid tropical countries where timber trees grow emc for air dried wood is 17-18% m.c. and in much of the more humid temperate areas it is about the same. In tropical countries emc within a closed building may be 10-14% and is usually about 12% while in temperate countries it is around 8-12%. Figure 6 shows recommended moisture contents for timber to be used in different conditions.

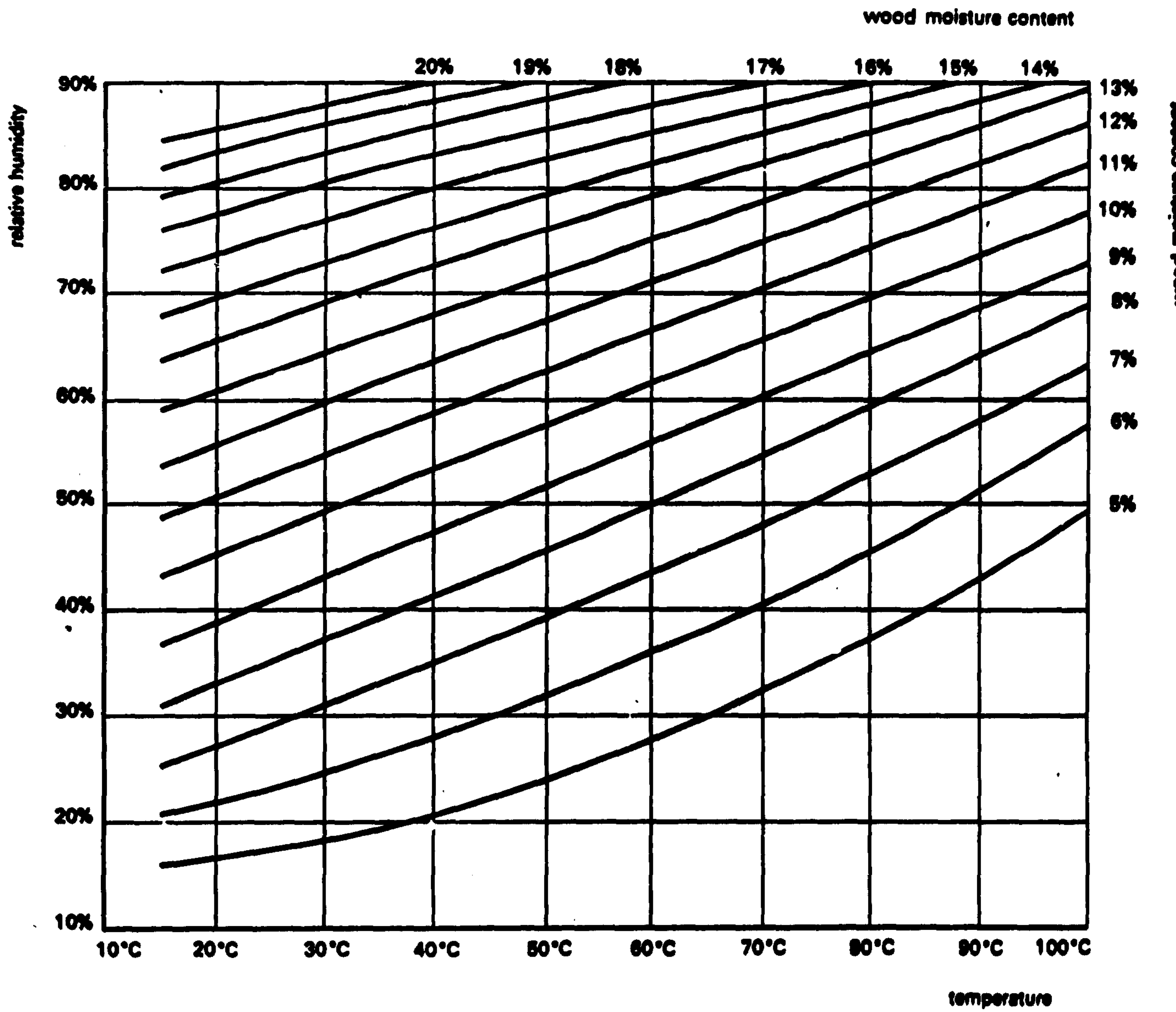


Figure 5. Chart showing the relationship between the moisture content of wood and the temperature and relative humidity of the surrounding air

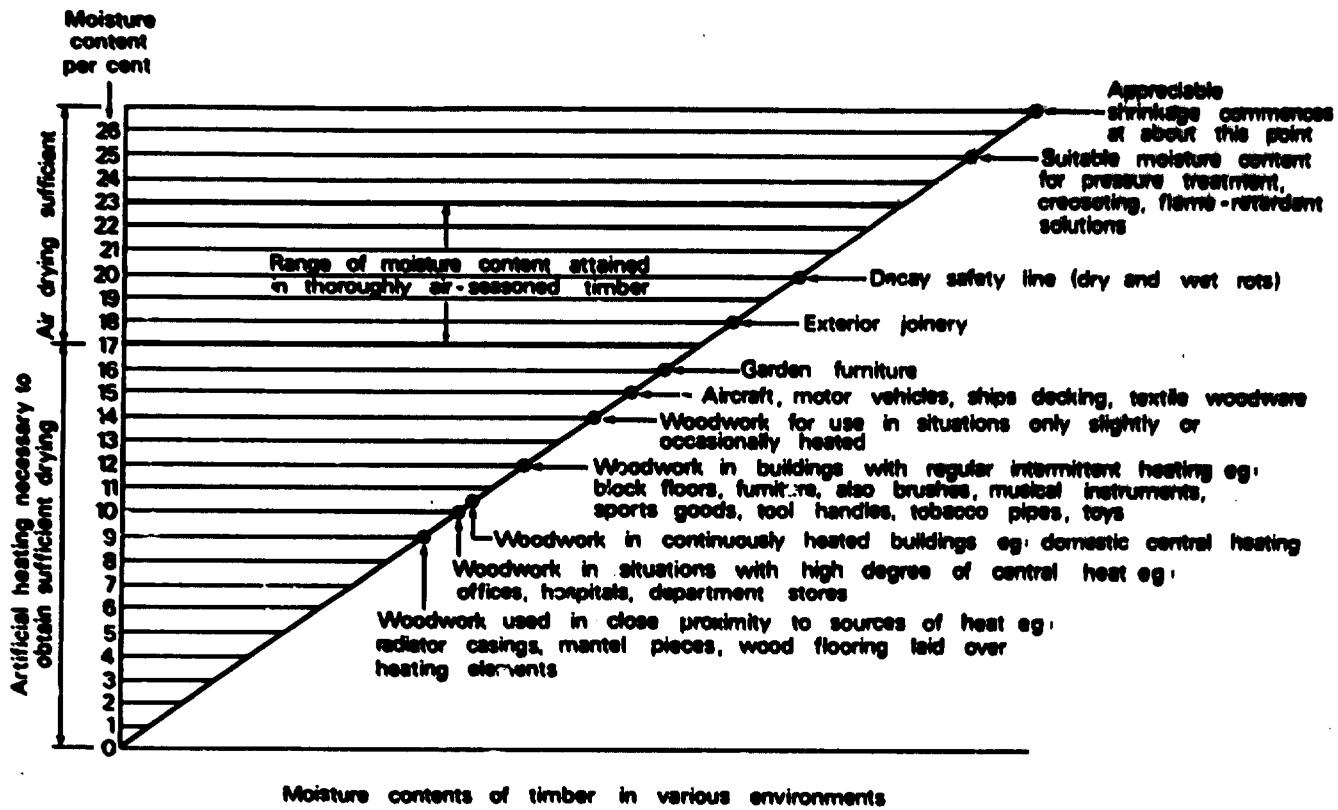


Figure 5. Typical moisture contents of timber in various environments. Note. The points shown are averages; actual values may vary by 1 or 2% moisture content from the point values indicated

It is clear, therefore, that air drying of timber will not dry it sufficiently for it to be used inside a building without further drying. Table 3 below shows the approximate shrinkage which would occur between 17% m.c. (the emc expected for air dried timber) and 12% m.c. (the emc expected inside a building).

Table 3. Shrinkage between 17% m.c. and 12% m.c. for High, Medium and Low Shrinkage Woods.

Species	Tangential Shrinkage %	Tangential Shrinkage In 12 inch (30cm) board	Radial Shrinkage %	Radial Shrinkage In 12" (30 cm)
Beech	2.97	5.6"/16 or 8.9 mm	1.41	2.8"/16 or 4.4 mm
Mahogany	1.41	2.8"/16 or 4.4 mm	0.78	1.56"/16 or 2.5 mm
Iroko	0.63	1.25"/16 or 2.0 mm	0.47	1"/16 or 1.6 mm

It can be seen from this table that the shrinkage is considerable and it is, therefore, essential for high quality furniture or joinery to use some form of kiln drying to dry to a lower m.c. than is possible by air drying. The only alternative is to put the timber to condition for a long period of time within that building or one at a similar temperature and humidity.

The Movement of Water in Wood

The methods by which water moves through wood are complex because of the complexity of the structure of the wood itself. It can move as liquid water, as vapour or as bound water through the cell walls. At any one time a combination of all three types of movement is operating. The physical laws governing each type of movement are complex and there is still some discussion on exactly how they operate. No attempt is made here to deal with them in detail.

In general, movement is fastest along cells, slower through pits from cell to cell and slower still through cell walls. Drying is, therefore, fastest along the grain and slower across it; it is slower from radial surfaces than from tangential ones.

If gums or other substances block cells, drying rate is slowed and high density woods dry slower than low density ones. Even within a species there are variations in density between different trees and within each tree which affect drying rate.

Except in the early stages of drying green timber, the rate of movement of water through the wood is the main factor limiting the rate of drying because evaporation and removal of water vapour from the wood surface is faster than movement through the wood.

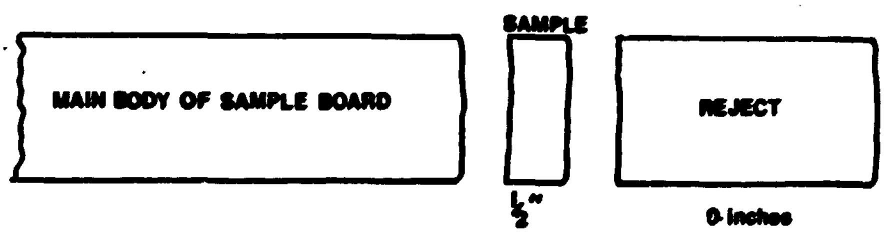
The rate at which a piece of timber dries is, therefore, related almost directly to how far the water has to travel to get to the wood surface and, therefore, to its thickness. Two inch (50 m.m. timber takes twice and 3 inch (75 mm) timber takes three times as long to dry as 1 inch (25 mm) timber. Mixing thicknesses in a kiln is, therefore, not a good thing to do; if it has to be done then the charge must be dried at the rate of the slowest timber in it.

The two main factors affecting rate of movement through the wood, other than the nature of the wood itself, are the temperature of the wood and the vapour pressure gradient between the centre of the wood and its surface. If the surface dries too quickly when the centre is still wet, stresses are set up which cause "case hardening" and other defects; there is also a tendency for the case-hardened layer of wood to slow down water movement through the outer layer of wood. Temperature increases the rate of diffusion of water vapour and the movement of bound water and, therefore, higher temperatures lead to faster drying.

The Measurement of water in Wood.

The most accurate method of measuring the average moisture content of a piece of wood is still the weighing and oven drying method where the wood is weighed, oven dried until all water is removed and weighed again. It is, however, a long process and requires the destruction of the piece of wood used. It only measures the m.c. of one piece of wood and at least five samples are required per stack of timber in order to get a reasonably accurate estimate of moisture content for the whole stack. Because wood dries faster along the grain, samples for moisture content determination should not be taken closer than 9 inches (225 mm) from the end of a piece of wood, and, therefore, each time a sample is taken it wastes about 10-11 inches of the timber. Each sample should consist of a complete cross section of the piece of timber about ½ inch (12 mm) wide avoiding knots and obvious defects) as shown in Figure 7.

FIGURE 7. SAMPLING OF TIMBER FOR OVEN DRYING AND MOISTURE CONTENT DETERMINATION



Moisture meters offer an alternative to the oven-drying method of moisture content determination; they use different methods of determining moisture content. The commonest are those which measure the electrical resistance of the wood between two probes driven into the wood. They are only accurate between about 30% m.c. and 0% m.c.; the lower the moisture content the higher is the resistance to the flow of electricity in the wood.

As the natural conductivity of wood varies from species to species each species requires to be calibrated and different scales are used for different species. Meters are usually supplied with short electrodes which can measure surface moisture content and "Hammer electrodes" which hammer longer probes into the centre of the piece of wood to measure internal moisture content. In this way they can measure gradients of moisture from the centre to the surface of the timber. They are moderately cheap to buy, they operate from small easily obtainable batteries and they are easy to carry to the timber and to use. Temperature has some effect on their operation and a small correction may be necessary for temperature. Readings of moisture content are higher at higher temperatures; instructions which come with the instruments specify what corrections are necessary.

A good electric moisture water should be equipped with the following:

- short probes for measuring surface moisture content
- A hammer electrode for measuring moisture content at least 35 mm into the timber
- easily obtainable and replaced batteries
- a built in battery strength check
- a table of species and scales on the meter which should be used for each species
- a good carrying case.

A method of calibrating an electric moisture meter is suggested in Annex 1, Appendix 3, if facilities are not available to use a constant temperature/humidity chamber, or an oven and saturated salts, which maintain constant, humidity and give accurately maintained equilibrium moisture contents. This latter method is the best if it is available.

Other types of meter use electrical capacitance or ultrasonic methods of measuring moisture content and require no probes.

<u>Air Drying of Timber</u>.

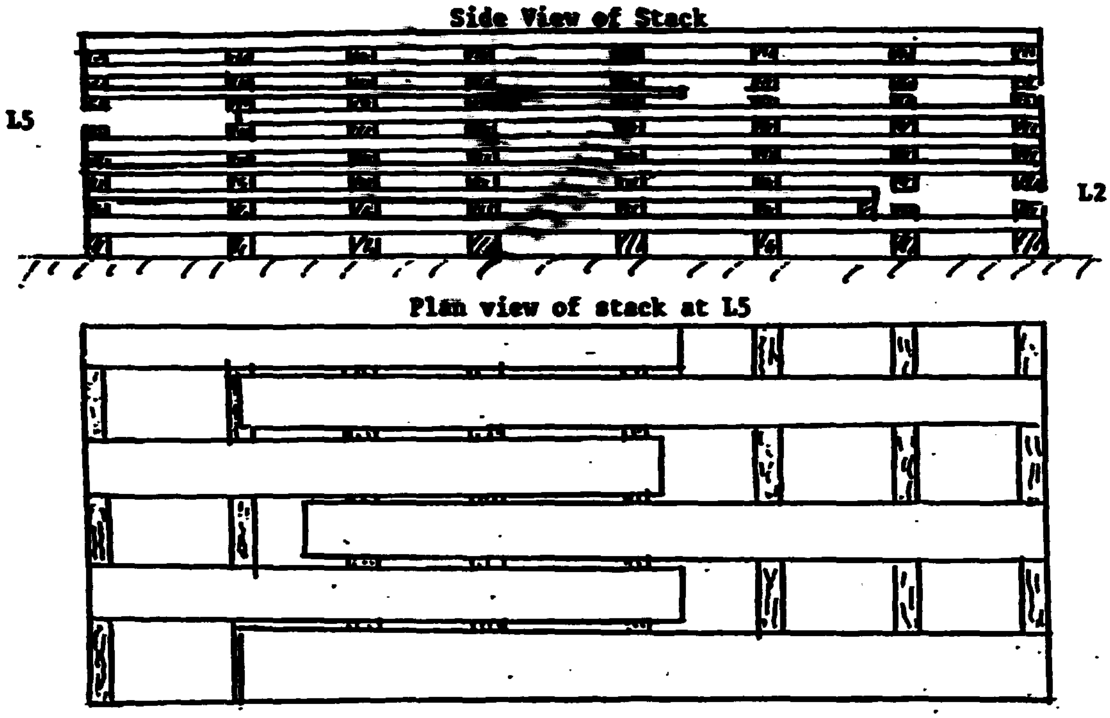
Air drying of timber has been used as long as sawnwood itself has been used. It is a relatively slow but effective method of drying timber to the emc which timber reaches in the air at the prevailing temperature and humidity.

The following are some simple rules to observe in air drying:

- Stack the timber in such a way as to keep it as straight and flat as possible during drying.
- try and ensure even air flow through the timber.
- keep sun off the ends of the timber and preferably, coat the ends with a wax or paint to prevent rapid end drying.
- In the tropics stacks should be oriented North-South to reduce the amount of sun on the ends of stacks.
- Cover the stack with a roof in a shed or with an individual stack cover to prevent rain getting into the stack or direct sunlight on top of the stack.

Figure 8 shows "block stacking" which is a method of building a square ended stack from pieces of timber of different lengths and avoiding overhang of the longer pieces and consequent distortion when drying. It is very important in stacking to ensure that "stickers" (the spacer pieces between the boards of timber being dried) are vertically above each other and transfer the load of the stack down to bearers forming the stack base. Ideally there should be an 18 inch (450 mm) air space under the stack to give under-stack ventilation.

Fig. 8. Method of "Box Stacking" different lengths of timber for drying.



Procedure

1. Build base of stack on firm land surface with stack bearers running across the stack and at least 100-150 mm (4-6 inches) square in section. Free air flow under stack is essential.

2. Length of stack should be the length of the longest piece of timber to be dried.

3. Stickers should run across the stack between boards in vertical rows 600-750 mm (2 - 2.5 feet) apart.

4. Shorter timber should alternately be pulled to each end of the stack as shown in plan view of L5 above to retain square ended stack with all board ends supported.

5. Overhanging board ends should be supported by additional short stickers where there is danger of drooping of the ends (L2).

6. Stacks should be covered with some waterproof cover to keep off direct rainfall.

It is essential to block stack timber going into a kiln in order to get a square erded stack to fill the space in the kiln and it is advisable to use the same method for air drying, particularly as air drying is often followed by kiln drying.

The arrangement of air drying stacks in a yard depends on prevailing wind and sun directions and on equipment used to move the timber. Books on timber drying show different methods and spacings but these need ideally to be worked out for each yard individually. Drying sheds are often used instead of stack covers on individual stacks. They often provide better protection from sun and rain but tend to be more expensive and to concentrate timber in a more restricted area which results in less air flow through the timber.

It should be remembered that in most parts of the world where timber is grown and used air drying will only dry the timber to 16-18% m.c. and further drying in a kiln is necessary for the timber to be used for furniture or joinery.

<u>Kiln Drying</u>.

Kilns are chambers into which timber stacks are put and temperature, humidity and air flow through the stack can be controlled to give faster drying and drying to a lower moisture content than is possible with air drying.

Different types of kiln use different methods of producing the required conditions and the most common ones are described briefly below:

<u>Steam Operated Kilns</u>.

One of the oldest methods of kiln drying is to use a boiler to produce steam which is then used to heat the kiln chamber by passing it through a series of heating pipes which heat air passing over them. If greater humidity is required the steam is fed straight into the chamber and the air humidity and temperature in the kiln rise. Fans are used to circulate air through the timber stack, inlet and outlet vents draw in some fresh air and let out humid air containing water removed from the wood.

This type of kiln is still extensively used where wood residues are available as fuel and fairly large quantities of timber need to be dried. The operation and maintenance of boilers requires skilled operators and the cost of installing this type of kiln tends to be high but fuel cost is usually low. Both heat and humidification are obtained in the one process.

<u>Hot liquid heated kilns</u>.

These kilns sometimes use hot water but, more often, a liquid such as oil with a boiling point higher than water to heat pipes passing through the kiln. They are normally operated by gas or oil-fired burners to heat the liquid. Control is relatively easy and boilers are not required but separate humidification units using a small steam supply or a rotating fan which "atomises" liquid water to supply humidity can be used.

Hot Air Kilns.

With these kilns the exhaust gases from an oil or gas burner are ducted through heating coils in the kiln. Control is on the heater itself and heat is only supplied when needed. A subsidiary system to provide humidity is also required. These kilns are relatively low cost compared with steam kilns but use high cost fuels fairly economically.

Direct Fired Kilns.

With these the exhaust gases from combustion are ducted straight into the kiln after passing through spark arresters, and heat the timber direct. They can only use natural gas (Methane) as a fuel where the exhaust gases are not poisonous. These kilns are, therefore, restricted to places where natural gas is available.

Dehumidifier Kilns.

These have been developed fairly recently (in the last 20 years) and use a method of removing water from the air circulating in a kiln by cooling it and condensing water out of it. The heat and the cool dried air are returned to the kiln and the water drained away. It is very energy efficient but can only be operated on electricity which is essential to operate the Compressor of the refrigeration plant and some additional heating as well. It is also required to power the fans, circulating air round the kiln. At present these kilns can only be operated at relatively low temperatures (50-60°C) because the refrigerants used do not operate at higher temperatures. Work is currently in progress to develop refrigerants which work at higher temperatures.

The advantages of these kilns are that they are low in capital cost and quite low in operating cost provided electricity is not greater than twice the prevailing cost of electricity in most Western European or North American countries. They are, however, slow compared with other conventional kilns and they tend to be useful for small drying operations. Very often the dehumidifier unit only is supplied and the purchaser builds his own kiln chamber.

Vacuum Kilns.

These are high cost kilns designed to dry quite small quantities of high value timber in a pressure chamber in which a vacuum is drawn. They work on the principle that as air pressure is lowered the boiling point of the water in the wood is lowered. Heat is applied by platens in between each layer of timber and the water is boiled out of the wood at low pressure. The process is rapid, three to four times as fast as conventional kilning and if done correctly results in very little defect in the wood.

Solar Kilns.

Solar driers trap and use the sun's energy to provide the heat to dry timber. Numerous designs have been built experimentally, some using solar heating only and some using dehumidification as well. They can be divided into "Greenhouse" kilns containing the timber in a greenhouse-type structure which traps the heat in the same chamber as the wood. Other kilns use a separate collector to heat air, which is then ducted into the chamber containing the timber.

Solar kilns are not as easily controlled as conventional kilns because solar energy is intermittent and affected by weather. These kilns are relatively slow in drying but, if properly operated, produce high quality drying at low cost. They are low in capital and operating costs, and, particularly in the tropics, they can prove very competitive with other methods of kiln drying. Annex 1. gives instructions for operating a solar kiln.

Methods of Operating and Controlling Kilns.

Most conventional kilns are operated using standard kiln schedules devised to dry timber at the fastest possible rate consistent with good quality drying. Fast drying woods can be dried at higher temperatures and lower humidities than slow drying woods. The Building Research Establishment in Britain has produced a "Timber Drying Manual" which lists a total of twelve different schedules with recommendations on which schedule should be used for a number of species used in Britain.

Schedules specify what dry bulb and wet bulb temperatures should be used for a certain moisture content of the timber. At high timber moisture contents temperatures are relatively low and humidities high and as moisture content of the wood drops bulb temperatures go up and humidities come down. Examples of schedules are given in Annex 1.

These schedules cannot be used directly for Dehumidifier kilns or Solar kilns because Dehumidifiers cannot use the high dry bulb temperatures specified and solar kilns do not have the necessary temperature control because they are dependent on heat from the sun. Similarly vacuum kilns would require different schedules but all other kiln types described here can use them.

In order to operate a schedule accurate measurement of the moisture content of the kiln charge is required. This can either be found by removing samples and oven drying and weighing or by using periodic moisture meter measurements at various positions in the charge or by constant monitoring of moisture content by inserting a number of probes in different samples in the charge at the beginning of drying, connecting them up by cables to a central moisture meter and monitoring moisture content continuously throughout drying.

The first method is probably still the most accurate; however, fewer than five samples, placed in different locations around the charge, including preferably the centre, are liable to give inaccurate results.

The removal of sample boards is made possible if stickers are notched around them, so that the weight of the stack is not resting on them and they can be pulled out of it at any time during drying.

Many modern kilns have automatic monitoring of temperature humidity and timber moisture content during drying and these are used to control automatically temperature and humidity and to alter them according to a selected schedule as wood moisture content drops, during drying. Such controls are excellent when they work well but they present problems when they do not work. Repair may require considerable electrical or electronic expertise. "Complicated" is not, therefore, always "best" particularly for small operations in areas remote from people with the necessary servicing and repair skills.

Operation of solar kilns is something of an art on its own. Some guidance and suggested methods of monitoring moisture content and controlling kilns are given in Annex 1. This Annex is written to be used separately from the guide if necessary and, therefore, contains some of the same tables and figures.

Presentation of the Results of Kiln Drying.

The progress and results of drying can be presented in graphical form. The normal drying curve recording the decrease of moisture content of the wood with time in the kiln is shown in Figure 9 and Figures 10 & 11 show kiln humidity and temperature variation with time and timber moisture content. In Fig. 11 the figures are for mean daily temperature and humidity while in Fig. 12 they are for hourly temperature and r.h. during the period 8.00 a.m. - 4.00 p.m. for the solar kiln concerned.

Reconditioning.

Timber dried in conventional kilns at fairly high temperatures may show signs of collapse or case hardening. These can be relieved by reconditioning or steaming the timber for up to 8 hours with low pressure steam when wood moisture content reaches about 17%. After reconditioning timber can then be further dried down to the final moisture content without much more defect occuring.

Preliminary "conditioning" steaming treatments may be recommended in some schedules for short periods before drying starts.

Defects in Kiln Dried Timber.

Many experienced users of timber prefer timber dried slowly, preferably as far as possible by air drying and then either conditioning of the wood in the situation where it is to be used or slow kiln drying to the correct moisture content.

The temptation for the kiln operator is to get charges through as fast as possible in order to earn more money, but this is counter-productive, as it can lead to severe defects and give kiln drying a bad name.

The following are some of the commoner defects and their causes:

Case hardening. This is not always obvious from visual inspection but is caused by too rapid drying of the surface wood when the wood below the surface is still wet and swollen. The wood on the surface is stretched beyond its elastic limit and sets in a stretched position. The centre then dries but the surface remains set. If the timber is then sawn or machined during use it tends to distort and jam on the saw. The "fork" test for case-hardening involves cutting a sample 1 inch (25 wide across the board or plank to be tested and then cutting the centre piece as shown below to give a fork.

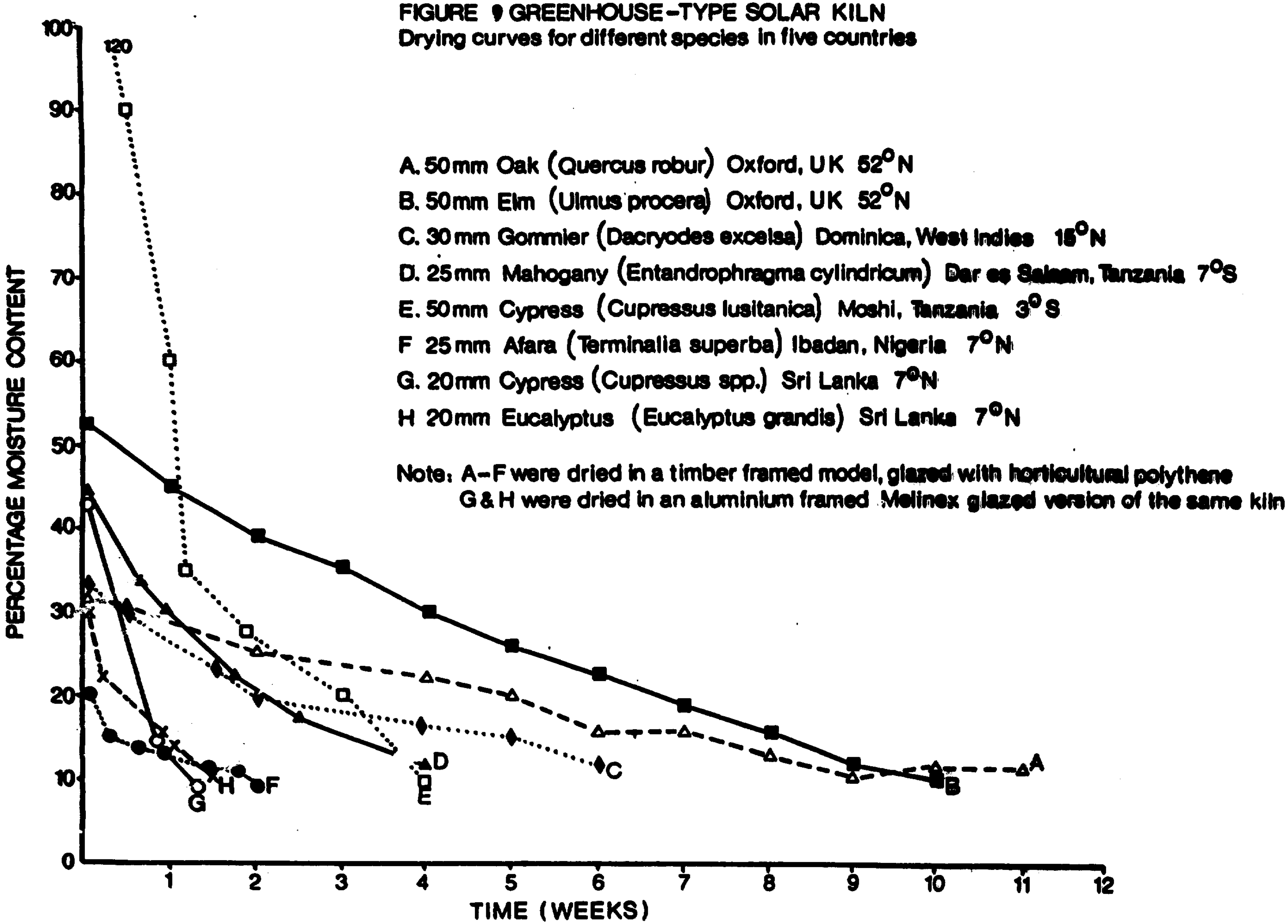


FIGURE 9 GREENHOUSE-TYPE SOLAR KILN
Drying curves for different species in five countries

Figure 10. MEAN DAILY HUMIDITY AND TEMPERATURES DURING DRYING OF TWO CHARGES
x DUKALLI from 35% - 78% mc
⊙ PURPLEHEART, MORA, LOCUST & KABUKALLI from 42% to 8% mc

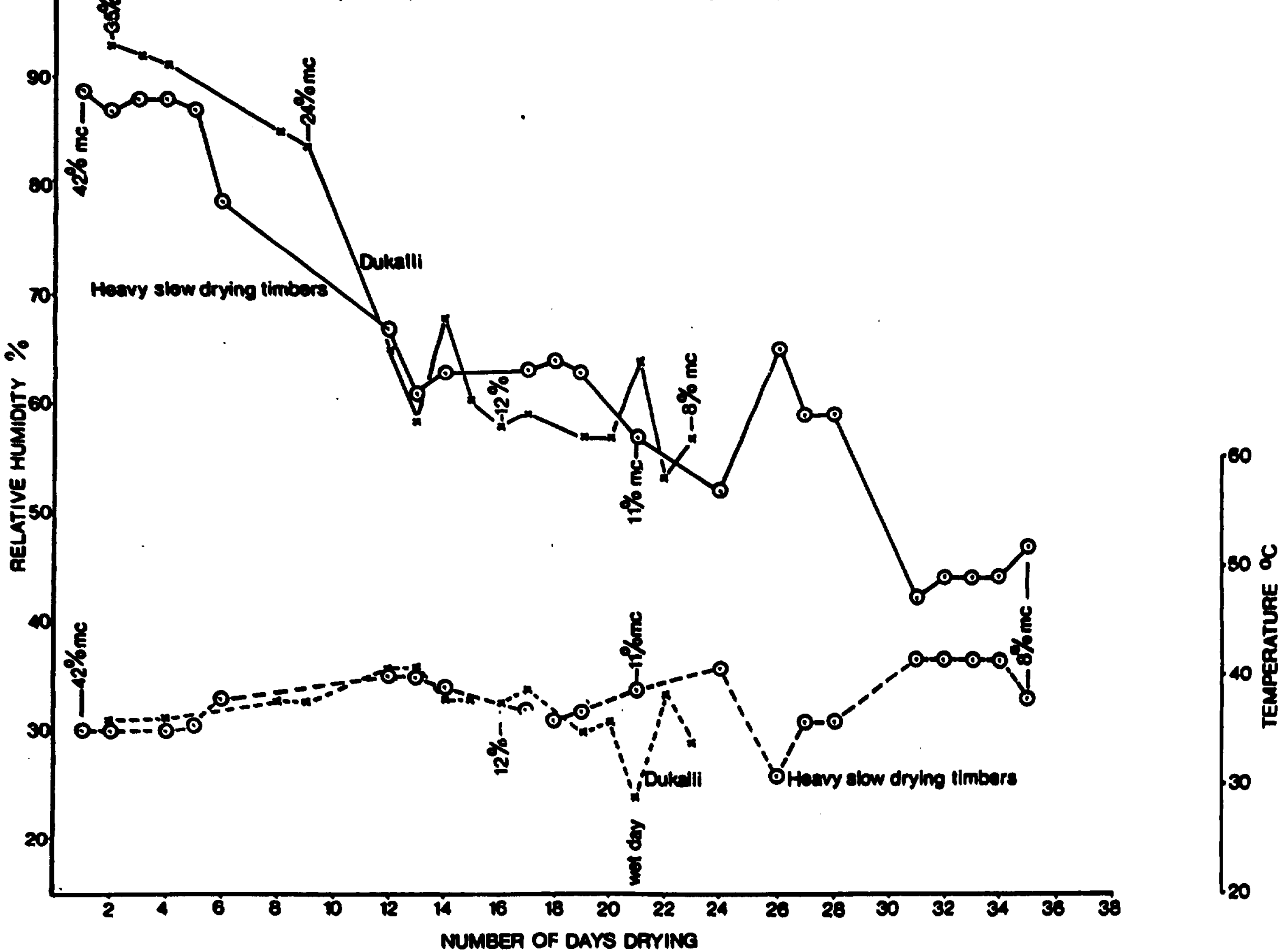
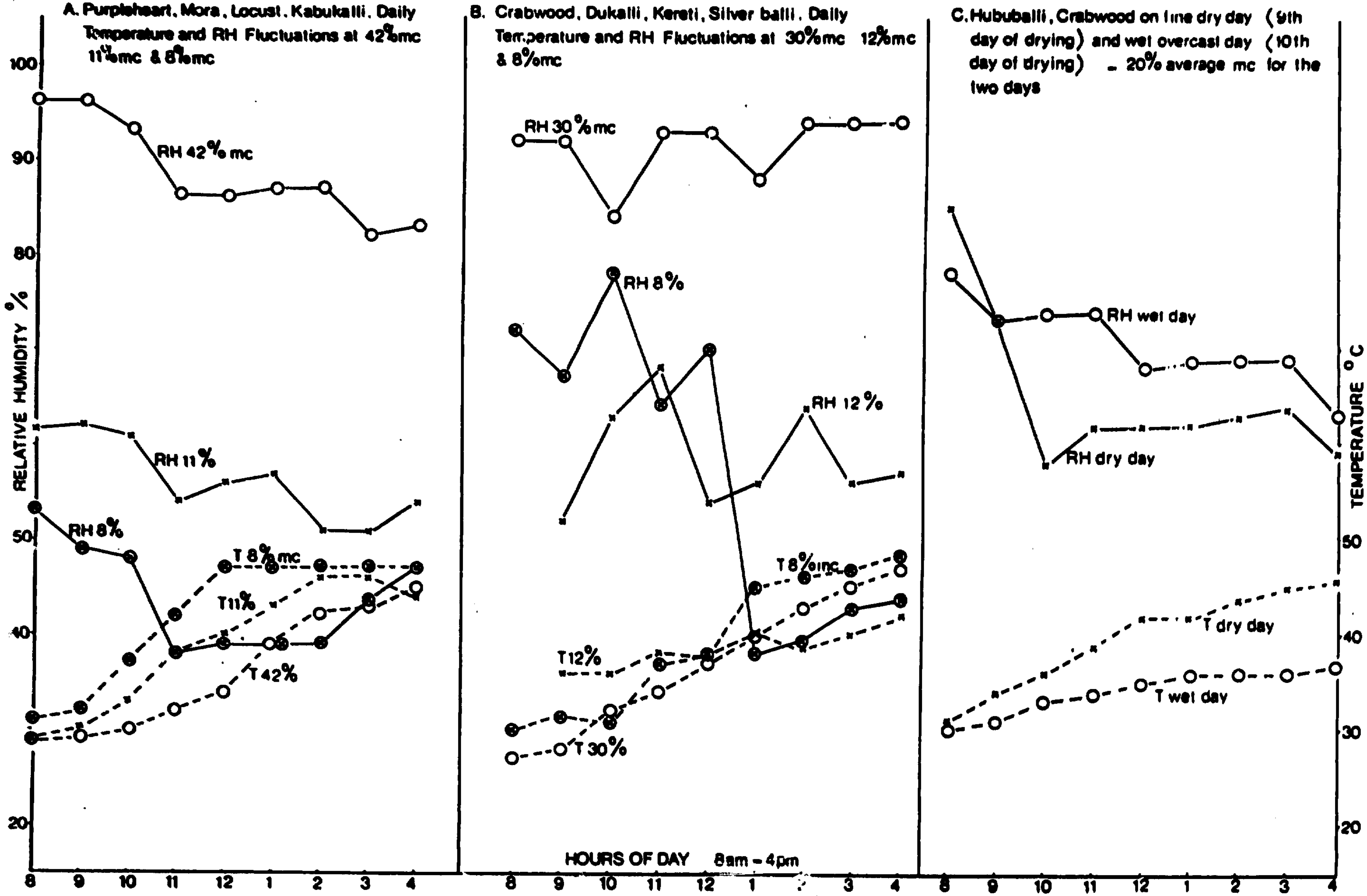
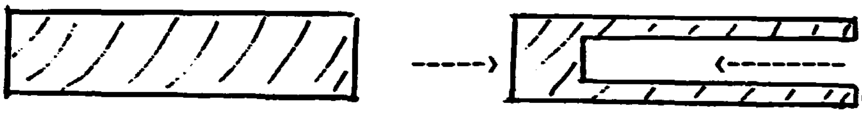


Figure 11. EXAMPLES OF HOURLY HUMIDITY AND TEMPERATURE FLUCTUATIONS AT DIFFERENT STAGES IN DRYING (A & B) AND ON WET/OVERCAST AND SUNNY DAYS (C).



<u>Fork Test for Case Hardening</u>.



Section cut across board.

centre cut out.

If the prongs of the fork bend in towards each other the timber is case hardened. If they do not it is not case-hardened.

<u>Collapse</u>. This again is caused by too rapid drying of the timber surface at the time when the interior is still damp. In this case the cells in some parts of the wood collapse because of restriction of air movement through pits. It can largely be restored by reconditioning. It is shown by corrugation of the wood surface into more and less severely collapsed bands of wood.

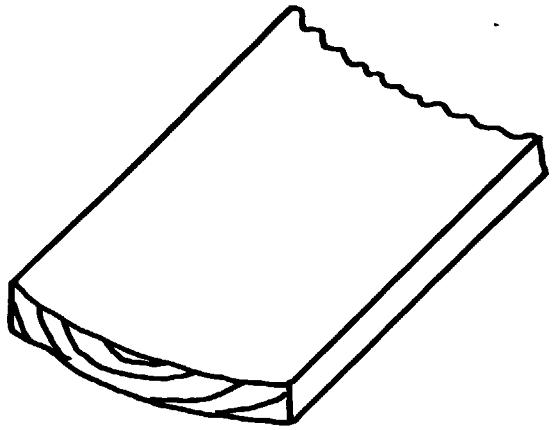
<u>Surface Checking</u>. Again this is caused by too rapid surface drying early in the drying process. Often fully dried timber has surface checks which opened up early in drying and then closed up when the interior of the wood dried, but the cracks remain and may show up during machining and finishing.

<u>End Splits</u>. These are common if the centre of the tree is included in the piece of timber. Very often they are inevitable and due to stresses in the log. End splits in other places are almost certainly due to too fast drying of the ends of the timber. End coating with wax or paint can help prevent this.

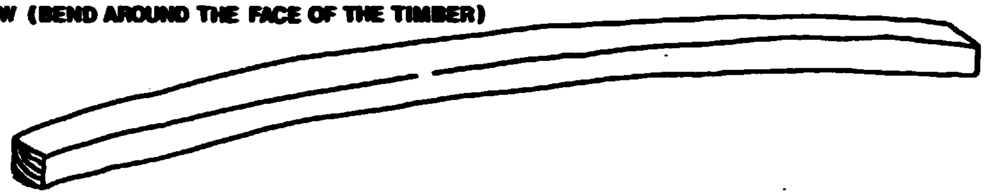
<u>Distortion</u>. (Cup, bow, spring and twist or warp).
These are illustrated in Figure 12 below. Cup is common on tangentially or flat sawn timber and is due to differences between radial and tangential shrinkage. It can be kept to a minimum by good stacking and drying at a high enough humidity in the early stages of drying. Bow is often due to poor stacking, leaving timber out in the sun unsupported along its length. It is usually avoidable but can sometimes result from reaction wood distortion in the timber. Spring is not normally due to seasoning and is more often due to tensions within the log before sawing which are released when the timber is cut. Twist (warp) is often the result of poor stacking, too rapid drying in the early stages and possibly irregular grain or reaction wood. It can be minimised by good stacking and slow drying in the early stages at a high enough humidity.

FIGURE 12MAIN DEFECT IN TIMBER

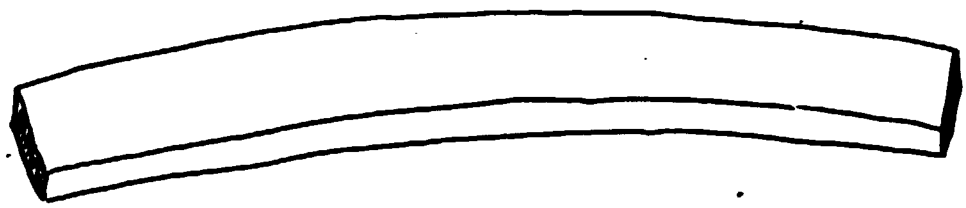
CUP



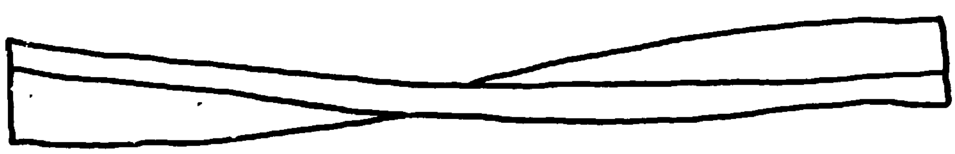
BOW (BEND AROUND THE FACE OF THE TIMBER)



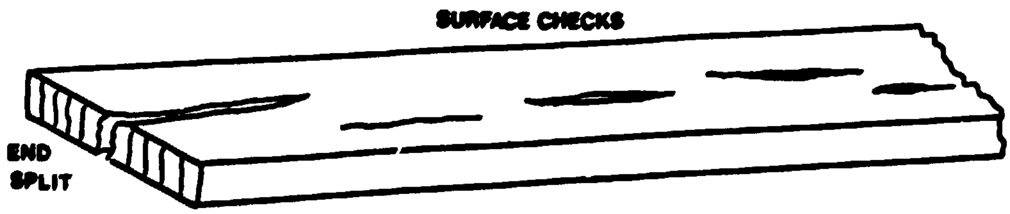
SPRING (BEND AROUND THE EDGE OF THE TIMBER)



TWIST (WARP)



SPLIT



Conclusion.

It cannot be over-emphasised that good quality timber products, cannot come from poor quality timber drying; if machining and finishing are poor then even with high quality seasoning good quality products do not result, but efficient drying to the correct moisture content is the first essential step. It comes from understanding the material and the processes that go on as wood dries. Properly seasoned wood not only holds its dimensions, it is easy to machine and work to a good finish and sands and polishes well.

This guide has attempted to give a background knowledge of the processes taking place as wood dries so that the reader can easily understand what is happening and learns what is essential and what is less essential. It is hoped it will help people to reason out for themselves what is happening when problems occur. It is not designed as a manual on how to operate particular kilns, information which should be available from the makers of the kilns or handbooks on kiln operation. Annex 1 deals with operating solar kilns on which there seems to be very little written.

The following, therefore, are some of the major points to remember in timber drying:

1. Determine what emc is required for the end-use of the timber and dry to that emc.

2. Keep moisture gradients in the timber from getting too steep, particularly in the early stages of drying. If in doubt keep air humidities in kilns high until the timber is down to about 17-20% m.c..

3. Get to know the different timbers you dry and what they will stand. Determine, if possible, what the radial and tangential shrinkage to 12% m.c. is.

4. Take enough samples in kiln charges to get a good average m.c. for the charge and dry the charge until the sample with the highest m.c. is dry.

5. Do not store dried timber in wet places. If necessary remove the stickers, block pile it and wrap it in polythene to slow down moisture pick up. If timber is to be exported after kiln drying make sure it is well wrapped and sealed to avoid moisture gain. The rate of uptake of water will depend, as with drying, on temperature, humidity, the permeability of the timber and its thickness. A medium density wood of average permeability and 25 mm thickness left in an atmosphere where e.m.c. is 17-18%, could be expected to pick up moisture from 12% m.c. to 16-17% in a month if not wrapped in a vapour proof sheet. Good practice should result, in time, in a good reputation and higher prices for the timber.

6. Attention to detail and care in the treatment of timber usually results in better profits. Even if it does not the timber deserves to be treated well; it has taken tens, if not hundreds of years, to grow and may be difficult to replace.

ANNEX 1

SOLAR KILNS AND THEIR OPERATION

The Characteristics of a Well Designed Solar Kiln

There are now many designs of solar kiln around the world, most of them research kilns and not in commercial production but increasingly they are becoming available as production models.

There are three main requirements of a kiln:

- it should be efficient enough in collecting and retaining solar energy to be able to dry timber to a low enough moisture content for immediate use after it leaves the kiln.

- it should be capable of providing timber drying of high enough quality to compete with that produced by conventional kilns.

- it should be capable of drying timber at a speed and at a cost that is competitive with other methods of kiln drying.

In addition to these three major requirements it is desirable that the kiln should be easy to construct and simple to operate; it is even more desirable that it should be reliable in operation, not liable to equipment breakdown, easy to maintain and easy to repair. Extreme efficiency of operation is not necessarily the most important criterion on which to judge a kiln; ease of operation, quality of drying and reliability are probably more important.

INSTRUCTIONS FOR OPERATING SOLAR KILNS

General

Solar kilns operate in a manner which is part way between kiln drying and air drying. In the former both temperature and humidity are controlled and, within the limits of the controls, any combination of temperature and humidity is possible. In dehumidifier kilns control is mainly by humidity and the temperature is relatively low.

With air drying both temperature and humidity are controlled by the weather and conditions are outside the control of the operator except that stack or shed orientation and protection of timber stacks from direct sun or rainfall by shed or stack roofs is possible; end sealing of timber and covering of ends of stacks are also possible to prevent too rapid drying and end cracking of the timber.

With solar drying it is not possible to control temperature except by increasing the temperature over ambient outside temperature using the "greenhouse effect" of the kiln glazing. The temperature inside the kiln will be controlled by the amount of radiation falling on the kiln, by the temperature outside the kiln and by the general efficiency of the kiln in trapping the radiation and converting it to heat. Unlike air drying, however, the solar kiln traps air and vents control the quantity of air allowed into and out of it. Humidity, therefore, is much more controllable than temperature and it is relative humidity which determines the final equilibrium moisture content (emc) of wood more than temperature.

The following table shows average emc of wood at different temperatures and humidities and the effects of relative humidity at temperatures typical of temperate and tropical climates and of internal conditions in a solar kiln.

TEMPERATURE	15°C	30°C	50°C
Relative Humidities	%	e.m.c. %	%
80%	18.25	16.8	15.25
60%	13.25	12.1	10.5
40%	9.5	8.5	7.25
20%	5.9	5.25	4.3

It is clear, therefore, that the relative humidity of the air passing over the timber very largely controls the e.m.c. of the timber but in a closed kiln a rise in temperature will lower relative humidity; it will at the same time speed up the attainment of the equilibrium moisture content by speeding up the rate of movement of water through the wood and its evaporation at the wood surface.

The ability, in the solar kiln, to control air exchange by opening or closing vents therefore gives an ability to control humidity particularly because water, which is being removed continuously from the wood, is adding to the humidity in the kiln unless it is vented. The most important factor affecting wood drying is, therefore, to a large extent controllable by the vents; an appreciation of this fact is necessary in operating a solar kiln.

Operation of vents in control of drying.

Air flow through the vents is controlled by air pressure inside and outside the kiln at each vent.

Vents need to be controlled to let enough air out to allow timber drying but not too much because damage will be done to the timber if humidity in the kiln is lowered too much too early in drying. Water often condenses at night on the glazed cover of the kiln and drains to the floor. If this is then allowed to drain out of the kiln a greater quantity of water can be removed in a given time by this condensation plus venting than by venting alone; the water is removed in a low energy state as a liquid rather than as high energy vapour and the kiln acts as a partial dehumidifier.

It is not always desirable to remove the condensed water on the floor because of the danger of lowering humidity in the kiln too rapidly and it may be desirable to leave the water on the floor to re-evaporate and humidify the kiln. Simple methods of collecting the water falling to the floor and either retaining it or draining it off, can be devised which will provide increased humidity control in the kiln. The simplest method is a polythene or PVC groundsheet which can be perforated to allow water to drain away or sealed to prevent it doing so.

Schedules for different timbers

Selected examples of conventional kiln schedules in Appendix I are taken from "The Kiln Operator's Handbook" by W.C. Stevens and G.H. Pratt to illustrate the operation of normal kilns. Fast drying woods are dried at faster, more severe schedules with higher temperatures and lower humidities than slow drying woods. Those liable to surface checking or warp require high humidities in the early stages of drying when the surface is drying and shrinking while the interior is still wet and swollen. To avoid case hardening it is important with slow-drying woods to avoid low humidities.

With a solar kiln it is not possible to adhere to a strict schedule and the art in operating the kiln is to ensure that the kiln dries the timber as fast as possible with a minimum vent opening to prevent heat loss and reduction of humidity below an acceptable level. In all wood drying most water is lost in the early stages of drying as the easily removed surface water evaporates and the free water within the cell lumens moves to the wood surface. Later in drying the amount of water evaporating from the surface of the wood is reduced since the rate of movement through cell walls is limited.

With fast drying woods it is important to remove sufficient moisture in the early stages of drying and if the timber is green the vents need to be opened fully and then gradually closed as drying proceeds. It is probably more efficient to use the kiln to complete drying after a preliminary period of air drying for these timbers since air drying is almost as fast as the kiln above 30-40% mc.

Used in this way the kiln will probably dry one and a half times the quantity of timber it would dry if drying from green in the kiln.

Slow-drying, difficult woods may not stand air drying under stack covers because of low humidities in the middle of the day, particularly in dry climates, in tropical dry seasons or in temperate summers. It may, therefore, be necessary to dry these timbers from green in the kiln. This can be done without causing defects even at high temperatures for a solar kiln provided that humidities are kept high in the crucial period when the wood surface starts drying below 25-30% mc. With these woods the vents need to be kept well closed particularly in hot, dry weather; provided this is done humidities will stay high enough. Measurements of humidity show that relative humidity drops in the middle of the day but rises again at night, particularly if fans are switched off at night. This relieves surface stresses in the wood and gives good quality drying of even the most difficult woods.

Later in the drying of both fast and slow drying woods it is possible to keep vents only slightly opened because less water is being removed from the wood surface and high temperature is required to move the water more rapidly through the wood.

Control of fans

There is little benefit to be gained from running fans at night except with charges of fast drying woods when they have high moisture contents and humidities are very high in the kiln. If humidities are over 80-90% during the day it is probably advisable to keep fans going at night, particularly if moulds or blue stain start forming on the wood. With slow drying woods and drier charges of fast drying woods fans should be switched off about an hour before sunset and switched on an hour after sunrise.

Monitoring of kiln performance

Periodic measurements of air temperature and humidity inside the kiln and, preferably also outside the kiln, plus measurements of wood moisture content are necessary to check kiln performance.

Measurements of temperatures and humidities at 8 am, noon and 4 pm are desirable, but not essential, while periodic moisture content measurements are essential.

Temperature and Humidity Measurements

Temperature and humidity measurements can be made using a single wet and dry bulb thermometer. Wet and dry bulb chart recorders are expensive but give a continuous record of temperature and humidity; they are worth installing if any research is to be done with the kilns.

Moisture contents of the wood

Moisture contents of the wood can be measured either by the oven drying and weighing method described in any text book on kiln drying or by moisture meter. Most moisture meters use an electrical resistance method which is accurate up to 30-40% mc but inaccurate at higher moisture contents; a few have scales which measure higher moisture contents but not accurately.

Kiln Records

Appendix 2 gives methods of keeping records and forms on which they can be kept and it is suggested that they are kept in full at least until the drying characteristics of the timbers for different thicknesses are well known. It is always essential to keep records of timber moisture content in order to know when drying is complete.

Figures

Figure 1 shows moisture content required for different uses in Britain. Other countries with different climates require timber dried to different moisture contents. For most of the humid tropics 12% mc is a reasonable average figure required for timber to go into a closed building.

Figure 2 shows how equilibrium moisture content of wood varies with humidity and temperature.

Table

Table 1 gives relative humidities in terms of wet and dry bulb temperatures.

Conclusions

Solar kilns are easy to operate in an acceptably efficient way. Provided vents are not opened too much with slow drying, refractory woods at the critical time when surface drying and shrinkage starts the quality of drying will be good. Optimum drying speed may be more difficult to achieve without practice but the basic techniques of achieving good quality drying are not difficult to acquire and very little operator time is needed to control these kilns.

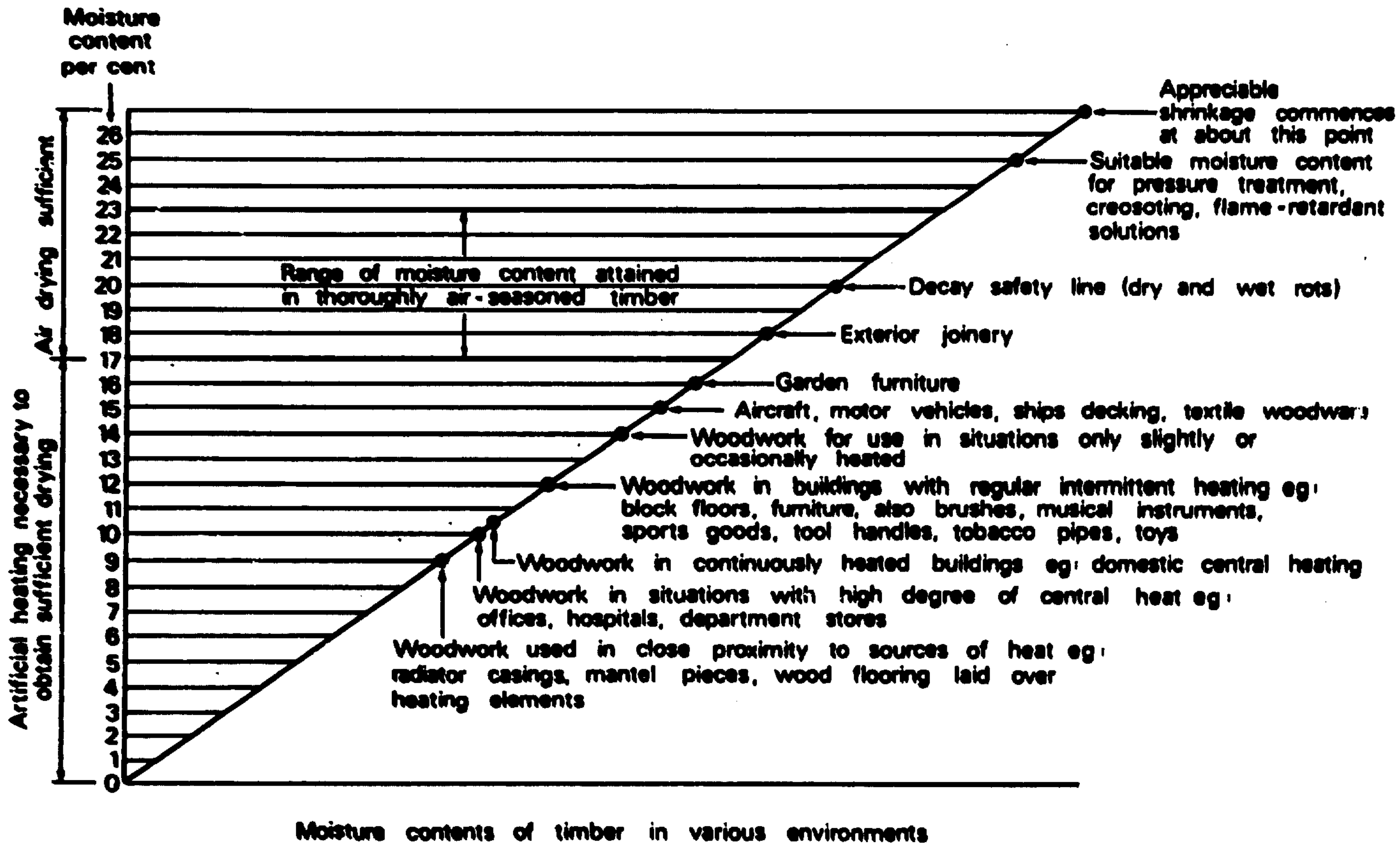


Figure 1. Typical moisture contents of timber in various environments. Note. The points shown are averages; actual values may vary by 1 or 2% moisture content from the point values indicated

Figure 2 Chart showing the relationship between the moisture content of wood and the temperature and relative humidity of the surrounding air

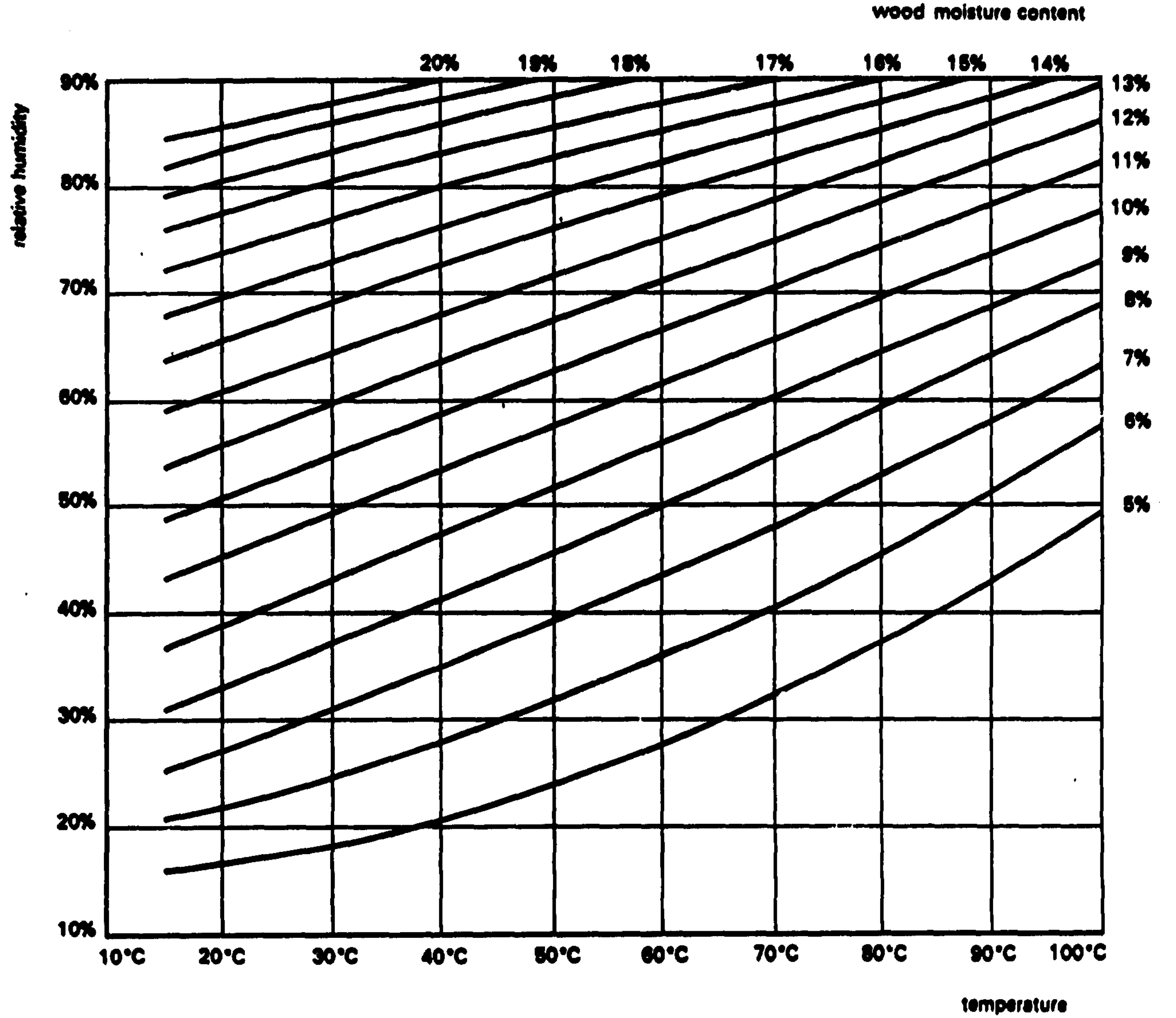


Table 1. Relative humidity-equilibrium moisture content table and saturated vapor pressure for use with dry-bulb temperature and wet-bulb depression —°C

Difference between wet- and dry-bulb temperatures in degrees Celsius

Temp. dry bulb (°C)	V.P. kPa	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0	22.0	24.0	26.0	28.0	30.0
0	0.6	91	82	73	64	56	47	39	31	22	14																				
		20.5	17.0	14.3	12.2	10.5	9.0	7.6	6.3	4.9	3.5																				
5	0.9	93	86	79	72	65	58	51	45	38	32	19	6																		
		21.6	18.4	15.9	14.0	12.3	10.9	9.7	8.5	7.5	6.5	4.4	1.9																		
10	1.2	94	88	82	76	71	65	60	54	49	44	33	23	14	4																
		22.4	19.5	17.2	15.3	13.7	12.4	11.2	10.2	9.3	8.4	6.8	5.2	3.5	1.3																
15	1.7	95	90	85	80	75	70	66	61	57	52	44	36	27	19	12	4														
		23.0	20.3	18.1	16.3	14.8	13.6	12.4	11.5	10.6	9.8	8.3	7.0	5.8	4.5	3.0	1.3														
20	2.3	95	91	87	83	78	74	70	66	62	59	51	44	37	30	24	17	11	5												
		23.4	20.9	18.8	17.1	15.7	14.4	13.4	12.4	11.5	10.8	9.4	8.2	7.2	6.2	5.2	4.1	2.9	1.6												
25	3.2	96	92	88	84	81	77	74	70	67	63	57	50	44	38	33	27	22	16	11	7										
		23.6	21.2	19.3	17.7	16.3	15.1	14.0	13.1	12.3	11.5	10.2	9.1	8.1	7.2	6.4	5.6	4.8	3.9	3.0	1.9										
30	4.3	96	93	89	86	83	79	76	73	70	67	61	55	50	44	39	34	30	25	19	15	12	8	4							
		23.7	21.5	19.6	18.0	16.7	15.6	14.5	13.6	12.8	12.1	10.8	9.7	8.8	8.0	7.2	6.5	5.8	5.3	4.5	3.8	3.0	2.2	1.3							
35	5.6	97	93	90	87	84	81	78	75	72	69	64	59	54	48	44	40	36	31	27	23	20	16	13	9	6					
		23.7	21.6	19.9	18.2	16.9	15.8	14.8	13.9	13.1	12.5	11.2	10.2	9.3	8.5	7.8	7.1	6.5	5.9	5.4	4.8	4.3	3.7	3.1	2.4	1.7					
40	7.4	97	94	91	88	85	82	80	77	74	72	67	62	57	53	48	44	40	36	33	29	26	22	19	16	13	8	3			
		23.6	21.5	19.8	18.3	17.1	16.0	15.0	14.1	13.4	12.7	11.5	10.5	9.6	8.8	8.1	7.5	7.0	6.4	5.9	5.5	5.0	4.5	4.1	3.6	3.1	2.0	0.7			
45	9.6	97	94	91	89	86	83	81	78	76	73	69	64	60	56	52	48	44	40	37	34	30	27	24	22	19	14	9	4		
		23.4	21.4	19.7	18.3	17.1	16.0	15.1	14.2	13.5	12.8	11.6	10.6	9.8	9.0	8.4	7.8	7.3	6.8	6.3	5.9	5.5	5.1	4.7	4.3	3.9	3.1	2.2	1.2		
50	12.3	97	95	92	89	87	84	82	80	77	75	71	66	62	58	54	51	47	44	40	37	34	31	28	25	23	18	14	10	6	3
		23.1	21.2	19.6	18.2	17.0	16.0	15.0	14.2	13.5	12.8	11.7	10.7	9.8	9.2	8.5	8.0	7.5	7.0	6.5	6.1	5.8	5.4	5.0	4.7	4.4	3.7	3.0	2.3	1.5	0.8
55	15.8	97	95	92	90	88	85	83	81	78	76	72	68	64	60	57	53	50	47	43	40	38	35	32	30	27	22	18	14	10	7
		22.8	20.9	19.4	18.0	16.9	15.8	15.0	14.2	13.4	12.8	11.7	10.7	9.9	9.2	8.6	8.0	7.5	7.1	6.7	6.3	5.9	5.6	5.3	5.0	4.7	4.1	3.5	2.9	2.3	1.7
60	19.9	98	95	93	90	88	86	84	82	79	77	73	69	66	62	59	55	52	49	46	43	40	38	35	33	30	26	22	18	14	11
		22.4	20.6	19.1	17.8	16.7	15.7	14.8	14.0	13.3	12.7	11.6	10.7	9.9	9.2	8.6	8.1	7.6	7.0	6.7	6.4	6.0	5.7	5.4	5.1	4.8	4.3	3.8	3.3	2.8	2.3
65	25.0	98	96	93	91	89	87	84	82	80	78	74	71	67	64	60	57	54	51	48	45	43	40	38	35	33	29	25	21	17	14
		22.0	20.3	18.8	17.5	16.4	15.5	14.6	13.9	13.2	12.6	11.5	10.6	9.8	9.1	8.5	8.0	7.6	7.1	6.8	6.4	6.1	5.8	5.5	5.2	4.9	4.4	4.0	3.5	3.1	2.7
70	31.2	98	96	93	91	89	87	85	83	81	79	75	72	68	65	62	59	56	53	50	47	45	42	40	37	35	31	27	23	20	17
		21.6	19.9	18.5	17.2	16.2	15.2	14.4	13.6	13.0	12.4	11.3	10.4	9.7	9.0	8.5	8.0	7.5	7.1	6.7	6.4	6.1	5.8	5.5	5.2	5.0	4.5	4.1	3.7	3.3	2.9
75	38.6	98	96	94	92	90	88	86	84	82	80	76	73	70	66	63	60	57	54	52	49	47	44	42	39	37	33	29	26	23	19
		21.1	19.5	18.1	16.9	15.9	15.0	14.1	13.4	12.8	12.2	11.1	10.3	9.5	8.9	8.4	7.9	7.4	7.0	6.6	6.3	6.0	5.7	5.5	5.2	5.0	4.5	4.1	3.8	3.4	3.1
80	47.4	98	96	94	92	90	88	86	84	82	80	77	74	71	67	64	61	58	56	53	51	48	46	44	41	39	35	31	28	25	22
		20.6	19.1	17.7	16.6	15.5	14.7	13.9	13.2	12.6	11.9	10.9	10.1	9.4	8.8	8.2	7.7	7.3	6.9	6.6	6.2	5.9	5.7	5.4	5.2	4.9	4.5	4.1	3.8	3.5	3.1
85	57.8	98	96	94	92	90	88	87	85	83	81	78	75	72	69	66	63	60	57	55	52	50	47	45	43	41	37	33	30	27	24
		20.1	18.6	17.3	16.2	15.2	14.3	13.6	12.9	12.3	11.7	10.7	9.9	9.2	8.6	8.1	7.6	7.2	6.8	6.4	6.1	5.8	5.6	5.3	5.1	4.9	4.5	4.1	3.8	3.5	3.2
90	70.1	98	96	94	92	91	89	87	85	84	82	79	76	73	70	67	64	61	59	56	54	51	49	47	45	43	39	36	32	30	26
		19.6	18.1	16.9	15.8	14.8	14.0	13.3	12.6	12.0	11.4	10.5	9.7	9.0	8.4	7.9	7.4	7.0	6.7	6.3	6.0	5.7	5.5	5.2	5.0	4.8	4.4	4.1	3.7	3.4	3.2
95	84.5	98	96	94	93	91	89	88	86	84	83	79	76	73	70	68	65	62	60	57	55	53	50	48	46	44	40	37	33	30	27
		19.1	17.7	16.4	15.4	14.5	13.7	12.9	12.3	11.7	11.2	10.3	9.5	8.8	8.2	7.7	7.3	6.9	6.5	6.2	5.9	5.6	5.4	5.1	4.9	4.7	4.3	4.0	3.7	3.4	3.1
100	101.3	98	96	95	93	91	90	88	86	85	83	80	77	74	71	69	66	63	61	59	56	54	52	49	47	45	42	38	35	32	29
		18.5	17.2	16.0	15.0	14.1	13.3	12.6	12.0	11.4	10.9	10.0	9.2	8.6	8.0	7.5	7.1	6.7	6.3	6.0	5.7	5.5	5.2	5.0	4.8	4.6	4.3	3.9	3.6	3.3	3.1
105	120.8	98	97	95	93	92	90	89	87	86	84	81	78	75	72	69	67	64	62	60	57	55	53	51	49	47	43	39	36	33	30
		18.0	16.7	15.5	14.6	13.7	12.9	12.3	11.7	11.1	10.6	9.7	9.0	8.4	7.8	7.3	6.9	6.5	6.2	5.9	5.6	5.3	5.1	4.9	4.7	4.5	4.1	3.8	3.5	3.3	3.0
110	143.2	98	97	96	93	92	90	89	87	86	84	81	78	76	73	70	68	65	63	61	58	56	54	52	50	48	44	41	38	34	32
		17.4	16.2	15.1	14.1	13.3	12.6	11.9	11.3	10.8	10.3	9.5	8.7	8.1	7.6	7.1	6.7	6.3	6.0	5.7	5.4	5.2	4.9	4.7	4.5	4.3	4.0	3.7	3.4	3.2	3.0
115	169.0	98	97	95	94	92	91	89	87	86	85	82	79	76	74	71	69	66	64	62	59	57	55	53	51	49	46	42	39	36	33
		16.8	15.6	14.6	13.7	12.9	12.2	11.6	11.0	10.5	10.0	9.2	8.5	7.9	7.4	6.9	6.5	6.2	5.8	5.5	5.3	5.0	4.8	4.6	4.4	4.2	3.9	3.6	3.3	3.1	2.9

Calculated from Hailwood-Horrobin single hydrate equation using parameters determined by Simpson (1973).

From: "Kiln drying of Western Canadian Lumber" by G. Bramhall & R.W. Wellwood, FORINTEK Canada Corporation.

APPENDIX I
KILN SCHEDULES

KILN SCHEDULE A

Suitable for timbers which must not darken in drying and for those which have a pronounced tendency to warp but are not particularly liable to check.

Moisture content (%) of the wettest timber on the air-inlet side at which changes are to be made	Temperature (Dry bulb)		Temperature (Wet bulb)		Relative humidity % (Approx.)
	°F	°C	°F	°C	
Green	95	35	87	30.5	70
60	95	35	83	28.5	60
40	100	38	84	29	50
30	110	43.5	88	31.5	40
20	120	48.5	92	34	35
15	140	60	105	40.5	30

KILN SCHEDULE B

Suitable for timbers that are very prone to check.

Moisture content (%) of the wettest Timber on the air-inlet side at which changes are to be made	Temperature (Dry bulb)		Temperature (Wet bulb)		Relative humidity % (Approx.)
	°F	°C	°F	°C	
Green	105	40.5	101	38	85
40	105	40.5	99	37	80
30	110	43.5	102	39	75
25	115	46	105	40.5	70
20	130	54.5	115	46	60
15	140	60	118	47.5	50

KILN SCHEDULE G

Suitable for timbers which dry very slowly, but are not particularly prone to warp.

Moisture content (%) of the wettest timber on the air-inlet side at which changes are to be made	Temperature (Dry bulb)		Temperature (Wet bulb)		Relative humidity % (Approx.)
	°F	°C	°F	°C	
Green	120	48.5	115	46	85
60	120	48.5	113	45	80
40	130	54.5	123	50.5	80
30	140	60	131	55	75
25	160	71	146	63.5	70
20	170	76.5	147	64	55
15	180	82	144	62.5	40

KILN SCHEDULE L

Suitable for fast drying softwoods

Moisture content (%) of the wettest timber on the air-inlet side at which changes are to be made	Temperature (Dry Bulb)		Temperature (Wet bulb)		Relative humidity % (Approx.)
	°F	°C	°F	°C	
Green	180	82	165	74	70
40	200	93.5	162	72	40

From; Building Research Establishment, Princes Risborough Laboratory,

APPENDIX 2

SOLAR KILN RECORDS

These are designed to record the performance of the kiln in relation to the climatic variations and the type and dimensions of timber being dried in it.

There are three record sheets, one recording the temperature and humidity inside and outside the kiln, one recording the moisture content of the wood in the kiln, and one recording seasoning quality. They should be completed as follows:

1. FORM 1. Temperature and humidity measurement sheet

Form 1A wet is for use where a wet and dry bulb chart recorder is used inside the kiln and a wet and dry bulb thermometer outside and Form 1B is for use where the wet and dry bulb thermometer is used for both inside and outside measurements.

In Form 1A wet and dry bulb readings are read off the charts and the temperature and the time of day at which it occurred are recorded for each day. The wet and dry bulb thermometer readings are taken at 8 a.m., noon and 4 p.m. or as near as possible to these times. The time must be constant each day and if these times are altered measurements must be consistently at 9 a.m., or whatever time is chosen.

It is desirable to make the recordings every day but if recordings with the wet and dry bulb thermometer are not possible at weekends they can be omitted.

2. FORM 2. Timber moisture content measurement sheet

Here measurements should be made every 3-5 days (avoiding weekends). With fast drying woods of small thickness drying is faster and measurements should be more frequent than with slower drying thicker timber.

Operation of the Moisture Meter.

The meter should be used as follows:

1. Open case and check battery strength with battery check device; if necessary replace batteries.

2. Check which scale on the meter to use for the species being tested.

3. Measure temperature of the wood to apply temperature correction.

4. Test moisture content of surface timber at each sample point using the short probes. Record moisture content for 'S' positions after applying temperature corrections.

5. Test moisture content of the interior wood using the hammer electrode. Record moisture content for 'L' positions after applying temperature corrections.

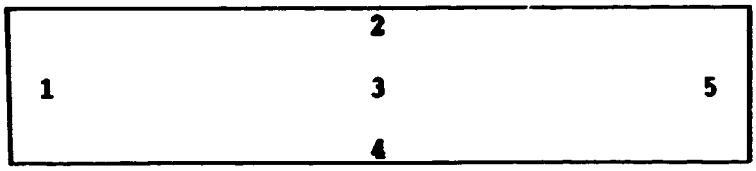
A method of calibrating the meter is suggested in Appendix 3 which can be used if facilities are not available to condition the timber accurately to different moisture contents in a constant temperature humidity chamber or conditioning oven.

The initial moisture measurement should be made by taking at least 5 samples, weighing, oven-drying and re-weighing to give the moisture content %.

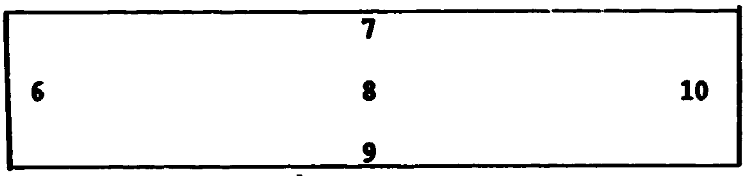
$$(MC\% = \frac{\text{green weight - oven dry weight}}{\text{oven dry weight}} \times 100)$$

After this moisture content measurements should be made with an electrical moisture meter. The measurements should be made at five points at each side of the kiln stack as shown in the following diagrams.

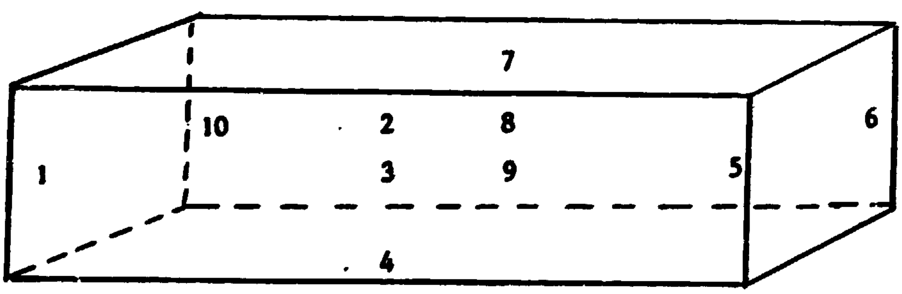
Facing stack from fan side



Facing stack from rear side



Three dimensional drawings of Stack



front of stack

Note. 6 will be the other side of the stack from 5 and at the same end; 10 & 1, 2 & 7, 3 & 8 and 4 & 9 are opposite each other.

The points should be 1 board from top or bottom of the stack for 2, 4, 7 & 9 and in the centre of the side of the stack for 3 & 8. Points 1, 5, 6 & 10 should be just over 30 cm (1 ft.) from the end of the board and 1, 3 & 5 and 6, 8 & 10 should be located in different pieces of timber.

Each measurement point should be marked on the wood with its number using pencil or felt pen.

If measurement is made using a moisture meter with a hammer electrode with long probes and an electrode with short probes the internal and external moisture contents of the wood can be measured as follows:

Knock the long probes into the wood at the positions marked using the hammer electrode for 2½ cm (1 inch). They should both be knocked into the centre of the edge of the piece of timber so as to measure as far as possible the moisture content of the wood in the middle of the piece of wood one inch from the edge. When the probes are removed, the holes should be plugged with matchsticks to prevent drying out of the wood through the holes left by the pins. The matchsticks can be removed each time measurement takes place.

Surface moisture content readings can be made using the short probes which are pushed into the wood near the long probes every time a measurement is made. For this the probes can be pushed into a different part of the wood each time.

Short and long probe measurements are then recorded on form 2 under position and S or L.

In this way gradients of moisture content between the inside and outside of the wood can be determined at different times during the drying period.

3. FORM 3. Seasoning quality record

Where possible this should be completed by a trained grader. Defects are divided into five categories and after examination of all pieces in the kiln charge the grader should tick the appropriate category column against each defect. Definition of category of defect can vary according to timber dimensions and the general drying properties of woods. The grader should judge whether defect is small or large for the particular species and timber dimensions and mark accordingly. No attempt, therefore, is made here to define categories for each defect but at the bottom of the form space is given to put in an average timber grade for the charge.

Case hardening should be measured using the prong test described in the main text of this guide and in most books on wood seasoning.

If the quality is recorded before and after drying it is possible to see how much of the defect occurs during drying.

FORM 1A

Temperature & Humidity Measurement Sheet
(Daily Measurement)

Species .... Charge No. .... Timber Thickness ....

Date	Inside Kiln				Outside Kiln						Remarks
	Dry bulb		Wet bulb		8 a.m.		Noon		4 p.m.		
	Max & time	Min & time	Max & time	Min & time	dry bulb	wet bulb	dry bulb	wet bulb	dry bulb	wet bulb	

FORM 1B

Temperature & Humidity Measurement Form
(Daily Measurement)

Species .... Charge No. .... Timber Thickness ....

Date	Inside Kiln						Outside Kiln						Remarks
	8 a.m.		Noon		4 p.m.		8 a.m.		Noon		4 p.m.		
	dry bulb	wet bulb	dry bulb	wet bulb	dry bulb	wet bulb	dry bulb	wet bulb	dry bulb	wet bulb	dry bulb	wet bulb	

FORM 2

Timber Moisture Content (Measurement every 3 - 5 days)

Measurement Sheet

Species .... Charge No. .... Timber thickness ...... Initial Moisture Content (by oven drying).....

Date	Position	1		2		3		4		5		6		7		8		9		10		Remarks
	Moisture Content %	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	

FORM 3

Seasoning Quality Record

Species .... Charge No. .... Thickness ....

Defect	Quality Category					Remarks
	1	2	3	4	5	
Surface Checks						
End split						
Bow						
Spring						
Cup						
Twist /Warp						
Collapse						
Case hardening						
Blue Stain						
Mould or other Stain						

Note: Category

1 = Very slight or no defect

2 = Slight

3 = Moderate

4 = Severe

5 = Very severe

APPENDIX 3

Calibration of Moisture Meters for Different Timbers

1. Take 5 samples 25 mm (1 inch) x 100 mm (4 inches) x 12 mm (½ inch) along the grain (see Fig. 7 in main text of the guide); they should be above 30% m.c.

2. With the moisture meter and hammer electrode measure moisture content at ¼ inch (6 mm) into the side grain of the samples and then knock the probes ½ inch (12 mm) into the sample, and record the measurement again.

3. Weigh each sample and record weights for each.

4. Oven dry the samples for <u>half</u> an hour, cool, and reweigh and remeasure mc with the moisture meter at both depths after the samples have cooled to ambient temperature inside a plastic bag to prevent reabsorbtion of moisture.

5. Oven dry for a further <u>half</u> hour, cool, reweight and remeasure.

6. Oven dry for <u>one</u> hour, cool, reweigh and remeasure.

7. Oven dry for <u>one</u> hour, cool, reweigh and remeasure.

8. Oven dry for <u>two</u> hours, cool, reweigh and remeasure.

9. Oven dry till weight is constant, cool, and reweigh.

10. Draw curve of moisture content against time after calculating mc at each measurement from the oven drying method.

11. Take average of ¼ inch and ½ inch (12 mm) probe depths at each measurement and compare with oven dry plot to get best scale to use on moisture meter.

Note: This method of calibration should only be used if equipment is not available to carry out calibration, using constant temperature/humidity chambers or saturated salts which give constant e.m.c's.