Air drying of timber
Information Pack

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1. Introduction

i. Aim of the information pack

This information pack details the main principles and methods of air drying a number of timbers grown and harvested in the Chilterns area. It is aimed at timber growers, processors and users who wish to dry a small volume of timber.

ii. The importance of drying timber

A number of our native timbers can be used for fencing, packaging, joinery, furniture, construction and a large number of internal uses. However, in many instances the timber must be dried before it is processed further. Correctly seasoned timber can be used in many more situations than green timber. It will also command a substantially higher price as the buyer can process it immediately. In order to maximise the profits it is necessary to minimise the wastage that can occur during drying. There is very little point drying a consignment of wood for 18 months if 50 % will be rejected by the buyer because of drying defects like longitudinal distortion, end splitting, cupping or staining.

This pack goes some way to help minimise the problems that can be encountered during air drying by providing practical information that has been gleaned from a wide number of sources.

iii. Reasons for drying timber

The main reasons for drying timber include:

- To prevent unacceptable shrinkage after installation
- To maximise strength, as mechanical properties of timber generally increase as it dries below 25 % to 30 % moisture content
- To reduce susceptibility to fungal decay. Timber maintained at less than 20 % moisture content is unlikely to be attacked by wood decaying fungi or sapstain.
- To make processed timber easier to handle, as seasoned timber is not as heavy as green timber
- To increase the effectiveness of preservative treatments. Many preservatives should only be applied when the moisture content of the timber has been reduced.
- To effectively glue, paint, stain, fill and polish timber
- To prevent the corrosion of metal fixings
- To meet legislation relating to the use of structural timber in buildings

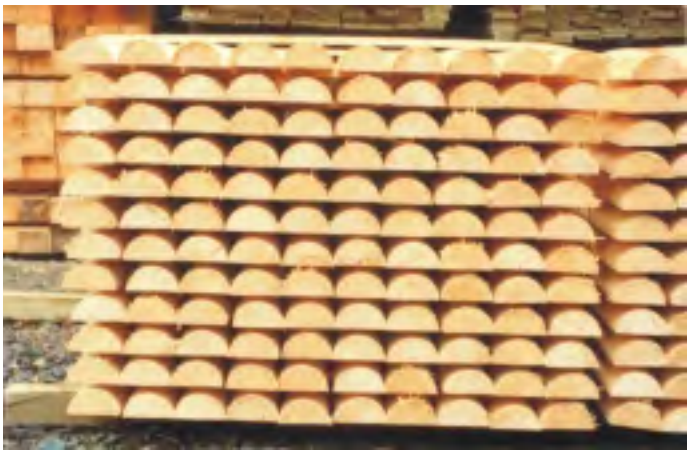

Plate 1: The drying of half round stakes before preservative treatment

1. Important concepts related to timber drying

i. Water in wood

Living trees contain a large amount of water. The moisture content will vary from season to season in standing timber and it will also vary between different parts of the tree such as the sapwood and the heartwood. It has been estimated that one cubic metre of freshly felled oak contains approximately 540 litres of water. The water is held in the cellular structure of the wood, which is made up of cell cavities and cell walls. The water held in the cell cavities is called **free water** whereas the water in the cell walls is called **bound water**.

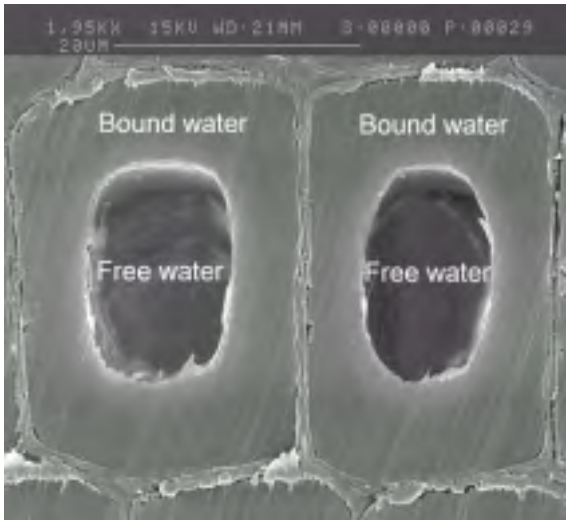

Plate 2: The location of free water and bound water in softwood cells

After felling and especially after conversion, green timber will start to lose moisture from any freshly exposed surfaces. The free water is lost before the bound water. This reduces the weight of the wood but does not affect its dimensions. The point at which the free water has been removed and the bound water remains is called the **fibre saturation point**. The moisture content of the timber when the fibre saturation point has been reached is usually between 25 % to 30 %. Timber that is dried to moisture contents below this level will exhibit some degree of shrinkage as the cell walls lose moisture.

ii. Equilibrium moisture content

Wood is hygroscopic and its moisture content is dependent on the temperature and relative humidity in the surrounding air. At a particular temperature and relative humidity, timber will eventually reach a constant or **equilibrium moisture content**. Knowledge of the temperature and relative humidity conditions is important, as they will dictate the lowest moisture content that can be achieved when drying wood out of doors. Even in a well insulated, centrally heated house the temperature and relative humidity can vary from day to day. Furthermore, knowledge of the equilibrium moisture content that timber component will attain in-service is necessary to ensure that the timber has been dried to an adequate degree before use.

iii. Shrinkage and swelling

Timber will shrink when its moisture content falls below the fibre saturation point. The degree of shrinkage will be dependent on the final moisture content that the timber reaches. Shrinkage varies considerably between timber species and this is shown in table1. Shrinkage values provided relate to drying timber from above 30 % moisture content to 12 % moisture content.

Table 1: Shrinkage and drying characteristics of some British grown timbers

Timber	**Approximate Shrinkage %**		**Drying rate**	**Drying characteristics**
	Radial	**Tangential**		
Ash	4.5	7.0	Dries fairly rapidly	Prone to end splitting
Beech	4.5	9.5	Dries fairly rapidly	Tends to check, split and distort
Birch	5.0	8.0	Dries fairly readily	Tends to distort
Wild cherry	3.5	6.5	Dries fairly readily	Pronounced tendency to distort
Sweet chestnut	3.0	5.5	Dries slowly	May caseharden or collapse if dried too quickly
Elm	4.5	6.5	Dries fairly rapidly	Some tendency to collapse or distort
Hornbeam	5.0	7.0	Dries fairly rapidly	Dries with little degrade
Larch	3.0	4.5	Dries fairly rapidly	Some tendency to distort. Dead knots may loosen
English oak	4.0	7.5	Dries very slowly	Tendency to split and check. Appreciable distortion. Some risk of honeycombing and casehardening
Scots pine	3.0	4.5	Dries rapidly	May blue stain if dried too slowly. Dead knots may loosen
Sycamore	3.5	6.5	Dries rapidly	Prone to sticker stain
Yew	2.0	3.5	Dries rapidly	Tendency for shakes to develop

(Source- Timber Drying Manual)

The following general assumptions regarding timber shrinkage should be remembered:

- Shrinkage only occurs below 30 % moisture content (fibre saturation point)
- Shrinkage along the grain is negligible in most cases
- Shrinkage across the width of a flat sawn board (the tangential direction) can be twice as much as shrinkage across a quarter-sawn board (the radial direction)
- Shrinkage associated with different sections cut from a log are shown in figure 1
- As a rough estimate, tangential shrinkage can be estimated as 1 % for every 3 % reduction in moisture content. For example a change in moisture content from 19 % to 13 % can result in a 250mm wide flat sawn board shrinking to 245mm. This may not seem much but it could have serious implications if floor boards were fixed at 19 % and subsequently dried to 13 % as this would result in the gap between them opening up by 5mm.

(Source: Timber Trade Education and Training Committee)

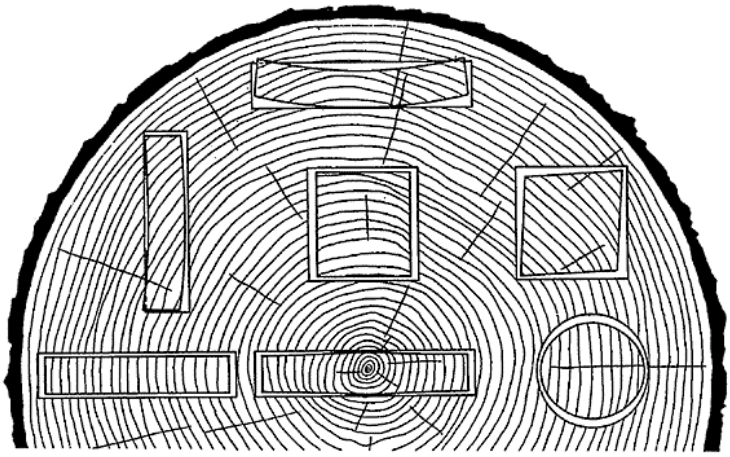

Figure 1: Shrinkage variation for different sections cut from log

iv. Climate changes in the Chilterns

The temperature and relative humidity of the air varies from month to month and from region to region. The rate of drying and the equilibrium moisture content that can be achieved by air drying outside and rate of drying is governed by these conditions.

To illustrate this point, table 2 shows the average temperature and relative humidity values for the High Wycombe area recorded between January 2000 and January 2001. The expected equilibrium moisture content that could be achieved by timber placed in these conditions is also provided.

Table 2: Average temperature and relative humidity measurements

Month (2000)	**Average temperature ˚C**	**Average relative humidity %**	**Equilibrium moisture content %**
January	4.9	90	20
February	6.6	88	19
March	8.0	84	19
April	8.3	85	18
May	13.0	77	17
June	15.7	77	16
July	15.8	76	15
August	17.4	77	14
September	15.2	84	17
October	11.0	88	18
November	7.3	90	19
December	5.8	90	19

Table 2 indicates that it is possible to dry timber outside to equilibrium moisture contents of 14 % in the summer and 20 % in the winter.

v. Equilibrium moisture contents for different end uses

Many timber components will be installed in conditions where their equilibrium moisture contents are lower than these air-dried values and so they will shrink. It is important that timber is dried to the moisture content that it will achieve in service otherwise there is a large risk that it will shrink or swell after installation. The following moisture contents are recommended for timber components intended for the different service conditions given in table 3.

Table 3: Equilibrium moisture contents for different situations

Example of end use	**In-service climate**	**Average moisture content %**
Fencing timbers, timbers used in gardens, stakes and poles.	External use fully exposed	20 % or more
Timbers for garages, sheds and out-buildings	Covered and unheated	12 % to 20 %
Protected external joinery	External and protected with surface finishes	12 % to 19 %
Woodwork in buildings that are mildly heated	Room temperatures of 12˚C to 21˚C	9 % to 13 %
Woodwork in continuously heated buildings	Room temperatures in excess of 21˚C	6 % to 10 %

(Source-extracted in part from BS 5268 and BS 942)

2. Methods of drying timber

i. Air drying

This is a method of drying timber by exposing it to natural atmospheric conditions. As such there is no control over drying rate as this will be determined by the prevailing weather (temperature, relative humidity, rainfall and wind speed), which will vary considerably between winter and summer. Some control over drying times and degrade can be achieved by correct stacking procedures of freshly sawn timber.

Air drying does not involve the need to burn fuels to dry wood thus conserving energy and reducing harmful atmospheric emmissions

The obvious advantage of air drying is its low capital cost in comparison to kiln drying procedures. Kiln operators often find that it is more economical to air dry timber to 25% to 30% moisture content if the material is likely to take more than 5 weeks to kiln from green due to its size or the drying characteristics of the timber.

However, it is important to remember that air drying can only be used to reduce the moisture content of timber to around 14 to 20 %. Therefore, for many applications kiln drying or storage in a controlled environment is a necessary final step in the drying process.

Plate 3: Air dying oak

ii. Kiln drying

Kilns are closed chambers in which air temperature, relative humidity and airflow can be controlled to dry timber to specified moisture content. There are many different types of kilns such as vacuum systems, traditional heat and vent type kilns and radio frequency dryers. The cost of installing and maintaining kilns may often be prohibitive unless throughput of timber is high. However, if the value of specific species is high enough, it becomes more feasible to kiln dry green timber.

Plate 4: A charge of timber for kilning, Timbmet Ltd, Oxford

iii. Solar drying

Solar drying offers an alternative to air drying and kiln drying. Although many believe that the climate in the United Kingdom is unsuitable for solar drying techniques, it is currently being used on a commercial scale in Oxford. It has been recognised as a viable alternative to expensive kiln drying when low moisture contents are required. *For more information on this method review the links provided at the back of this pack*

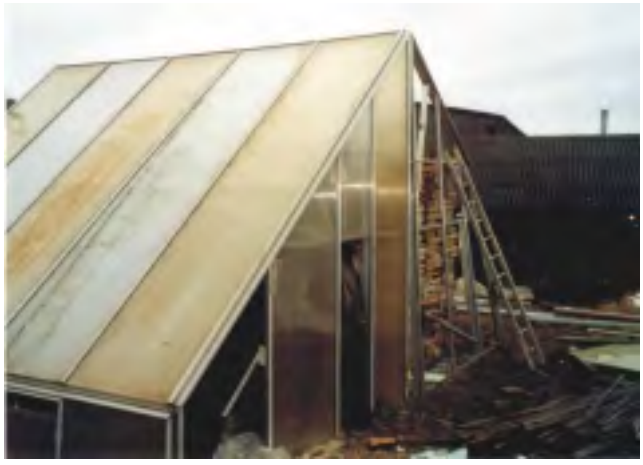

Plate 5: A solar drying unit being filled with timber

iv. Dehumidifier drying

Dehumidifier kilns are also suitable for drying timber on a small scale. Dehumidifier units and fans can be incorporated into insulated shipping containers or refrigerated delivery lorry boxes. The advantages of this system include low capital costs, low running costs and low levels of degrade. *For more information on this method review the links provided at the back of this pack.*

4. Practical issues for air drying timber

The following sections describe procedures that must be taken into account when attempting to air dry timber

i. Preparing the site for air drying

The site chosen for the drying stack should be free from rubbish and not be overgrown with vegetation. Once allocated, the selected site should be kept clear of debris throughout the drying period. Although, a windy site may be preferable, nearby trees and buildings can provide shade in the summer and some protection from driving rain. Remember that the stack may be in this position for a number of years and cannot be easily moved unless a forklift is available. The stack could be located in an open sided barn structure or even a carport.

ii. Bases

Ideally, a well designed concrete base should be used that allows water to drain freely. However, a well packed level hardcore base may be a more economical solution. It is important that the drying stack does not sink as this can cause uneven drying and may make the stack unstable.

iii. Supporting timbers

The weight of the stack should be evenly distributed on the base using sound, preservative treated wooden sleepers or concrete posts. These should be spaced at intervals of 400mm to 600mm (16" to 24") and can have additional timbers fastened to their upper surface to raise the stack to between 150mm and 200mm (6"and 8") above the ground. Timber pallets can also be used to raise the stack to a suitable level above the base. It is important that the supporting timbers do not rot or transfer moisture to the drying stack. Use naturally durable timber or preservative treated timber in conjunction with a damp-proofing material.

Plate 6: A well packed hardcore base with timber sleepers

iv. Constructing the stack

Drying can be quite fast in warm weather. Therefore, if sawing in mild spring and summer it is recommended that the sawn timber is stacked within 12 hours. Sawdust should be removed from the surfaces of the boards before they are stacked. The drying stack should have flat, square ends to promote even drying. Timber stickers that promote airflow through the stack and allow evaporation from the exposed surfaces separate each layer of timber from the next. Airflow is necessary to carry evaporated moisture away from the drying surfaces. If the air surrounding a piece of wood is stationary the rate of evaporation will reduce as the air becomes saturated with water vapour.

v. Stickers

Stickers should be aligned in perfectly vertical rows in line with the supporting base timbers. Alternatively space stickers at 300mm (12”) intervals if truly vertical rows cannot be achieved. Stickers can be any softwood species or light coloured hardwood (e.g. beech). They are usually 18mm (3/4") thick and are about 18mm to 32mm (1-11/4") wide. Timber stickers must be fully air dry before building the stack if you are to avoid staining. Kiln dried timber stickers with very low moisture contents will dry the region under the sticker very quickly and also cause staining. Most stickers are rectangular although shaped stickers allow some air movement under the sticker and encourage the wood under the sticker to dry faster. It is important that they are of uniform thickness to promote even drying in the stack and to minimise distortion of the timber.

Plate 7: Align stickers with supporting timbers and use appropriate spacing

Plate 8: Dry softwood stickers used for separating each layer of timber

The space between stickers depends on the thickness of the drying timber. Timber that is 25mm (1”) generally requires closer sticker spacing than 50mm (2”) timber in order to reduce distortion. The reason for this is that thin boards can distort under their own weight and will not dry straight unless they are adequately supported.

Fewer stickers are used with softwoods than hardwoods. For 25mm (1”) softwood the sticker spacing can be every 1200mm (4’) (use wider stickers to prevent crushing) whereas the sticker spacing for hardwoods is commonly between 400mm and 600mm.

It is important, when building the stack, to leave a space of approximately 25mm (1") between boards in each layer. Do not mix timber of different thicknesses in the same layer.

Plate 9: Leave spaces between boards in each layer

vi. Stack sizes

The height of the stack depends on the amount of wood being dried. It is also a factor to consider from a safety point of view. A number of rows of timber can be used to make up a lift. Lifts enable different timbers of various sizes to be incorporated in the same stack. Each lift should be made up of the same timber species and each layer should contain timber of the same thickness. Each lift can be 900mm to 1200mm (3' to 4') in height and 1200mm to 1800mm (4' to 6') wide. The lifts in a stack can be separated by 100mm x 100mm (4" x 4") timbers spaced at 600mm (24") and in line with the stickers and the base timbers). Each drying stack can be comprised of two or three lifts of timber. The width of the stack may need to be governed by the size of the lorry bed that it will be subsequently transported on. Very wide stacks should be avoided, as the timber in the centre will dry slower than the outer boards.

Each lift should be made up of one timber species and thickness. Slower drying timbers and thicker boards should be placed in lifts at the bottom of the stack. Faster drying timbers and thinner boards should be placed in lifts at the top of the stack.

The length of the longest board governs stack length. The ends of the stacks should be square with no overhang (this is called box end piling). This can be achieved by laying full length boards on the bottom and outer edges. Then laying shorter boards from alternate ends of the stack. Short boards can be used to fill gaps and spaces can be left in the stack to promote airflow. It is important to support all boards with stickers.

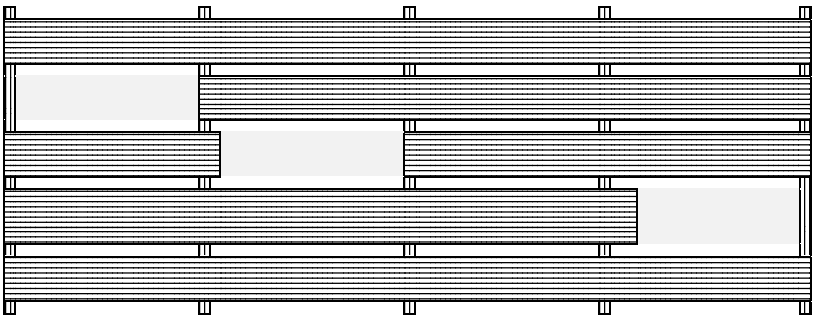

Figure 2: Plan view of a timber drying stack showing how different lengths of timber can be incorporated in the stack.

Flues can be built into stacks by leaving a larger gap between adjacent pieces. Flues are considered to increase the rate of drying and are useful if the timber can cope with fast drying. They are often used with stain-prone softwood to promote better air circulation and rapid drying. Better drying can also be achieved by leaving a minimum of 600mm (2') between adjacent stacks.

vii. Weighting stacks

Experience indicates that the stacks should be weighted to minimise distortion. Some people use heavy timbers while others use concrete blocks. A safe alternative is to use the web straps that lorries use as load binders. These work very well on timber and should be tightened on a regular basis. The straps can be fitted around every supporting timber at the bottom and aligned 100mm x 100mm (4" x 4") timbers placed on the top of the stack. You will only need five straps per 2400mm (8') long timber stack.

viii. End sealing

The ends of the boards must be protected to minimise end splitting by rapid moisture loss. This can be achieved by applying proprietary end sealing products (usually wax emulsions). Paint, such as leafing aluminium primer, can also be used for end sealing.

Some timber processors nail thin sections of wood, metal or plastic to the ends of timber to reduce the likelihood of end splitting. However, wooden cleats should not be used when drying timber below 30 % moisture content as they can actually encourage the drying timber to split. Thin plastic or metal end cleats that buckle as the timber shrinks do not promote splitting and may prevent rapid moisture loss in the early stages of drying.

Plate 10: Ends coated with wax

ix. Protection of stacks

Stacks that are left in the open should have some form of secure roofing structure to prevent ingress of rain water. This may take the form of wide cladding boards, plywood or corrugated plastic or polythene sheets securely fixed to the top of the stack. Avoid using iron sheeting as this may cause unsightly staining with some timbers. Any roof structure should allow water to drain well clear of the stack.

Some protection may be required from sunlight and wind to prevent degradation and uneven drying. This can be achieved by hanging shade cloth or plastic mesh down the sides of the stack. This material also prevents rain blowing into the pile.

Plate 11: Shade cloths protecting lifts of drying timber

x. Other stacking procedures for air drying

Piling in log form

Planks can be piled straight from a through and through or plain sawing procedure in log form. This practice minimises handling and is desirable when there is a demand for planks cut from the same log so they can be readily matched for figure and colour (see cover photograph). The stack will only be as large as the original log and planks tend to dry faster as each pile is fairly narrow. Consequently, thinner stickers should be used with timbers that are susceptible to surface checking.

Plate 12: Piling in log form

End racking

Rapid surface drying can be achieved by placing boards vertically against a support, such as a fence, in the shape of an X or inverted V. This is usually only undertaken with species that are susceptible to stain and sticker marks such as sycamore. End racking ensures good air circulation to all surfaces but can cause casehardening in some species such as oak.

Plate 13: End racking timber using a fence

xi. Health and safety issues

Timber stacks should always be located on firm foundations to prevent the timber sinking into the ground and the stack becoming unstable. Design the stack height and width for maximum stability and ease of handling. Narrow, high stacks may become unstable in high winds and should be tied together with long bolsters to improve stability. The roof structure, weights and straps should also be secure and checked regularly.

5. Monitoring the progress of the air drying process

i. Drying times

A rule of thumb for the UK is that 25mm (1") thick material will take one year to dry, 50mm (2") thick material will take two years to dry and 75mm (3") thick material will take 3 years to reach equilibrium moisture content by air drying. In addition to thickness, drying times depend on the characteristics of the timber being dried, climatic conditions (temperature and relative humidity) and airflow through the stack. Some timbers will have higher green moisture content than others. Furthermore, heartwood and sapwood from the same tree may have very different drying characteristics.

The time of year that the green timber is processed and stacked will also influence the time required to dry timber to equilibrium moisture content. Green timber stacked in warm spring and summer months will dry much faster than timber stacked in late autumn or winter. This is due to the effective air drying days during each month.

If it is possible to choose the season to commence air-drying timber then it is advisable to stack hardwoods in the winter when the drying conditions are mild to prevent splitting. Softwoods can be stacked in spring when the rate of drying is more rapid and sapstain can be prevented.

It is not possible to accurately gauge drying times due to the wide range of influencing factors. The following times are based on the experience of drying timber in the Chilterns area:

- Softwoods. 25mm (1") thick Scots pine that is stacked in April can reach 20 % moisture content by July to August if the summer months are warm and dry. 50mm (2") stock can reach similar moisture contents by early October
- Hardwoods. 25mm (1") thick English oak if piled in early autumn can reach 20 % moisture content in about 10 months.

ii. Assessing the progress of drying

It is useful to know the moisture content of the timber at the start and at regular intervals during the drying procedure. This allows the timber to be left in the stack for the optimum time period. Each lift should contain a couple of pieces that can be easily withdrawn for moisture content assessment. The simplest method is to use a short sample board that is protected by a cover board. The sample board should be weighed regularly (every three weeks) and returned to the stack. When the sample board achieves a constant weight over three subsequent weighings the stack can be considered to be seasoned and at equilibrium moisture content with the drying environment.

iii. Determining moisture content

For the determination of moisture content an electrical resistance type moisture meter can be used. However, many of these devices are only useful towards the end of the drying period, as they tend to be more accurate below fibre saturation point (25 % to 30 %).

Accurate measurement of the moisture content of the drying wood can be made by cutting a section 300mm (12”) from the end of a sample board. The piece should be full thickness and full width but only 25mm (1”) along the grain. This needs to be accurately weighed and the weight recorded (the wet weight). The piece should be placed in an oven at 105˚C for about 24 hours. To determine if the section is dry it should be reweighed, put back in the oven for another hour and weighed again. If the weights are the same, then the piece is oven dried (the oven dry weight).

Use the following calculation to determine the moisture content:

$$\text{Moisture content (\%)} = \frac{\left(\text{Wet weight - Oven dry weight}\right)}{\text{Oven dry weight}} \times 100$$

Remember that in the UK it is generally considered that air-drying outside can reduce the moisture content of timber to an average of 20 %.

iv. Storage after air drying

When the lowest, uniform equilibrium moisture content has been achieved by drying the timber out of doors, it is advisable to move the timber to a covered storage area. This may be a shed, a workshop or a garage. Further drying in the covered storage area can take place with the correct conditions of relative humidity and temperature.

If covered storage is not available, then the timber should be stored outside with a polythene sheet covering the top of the stack. This should be kept away from the top surface of the stack using timber battens. The stack can be removed from stick and close piled in order for the stickers to be reused.

6. Reducing degrade and distortion

i. Drying defects

Defects that arise during the drying of timber have a direct impact on the cost of air drying because they reduce the value and the yield of useable dry timber. For the purposes of this information pack, the different types of defects are given alongside possible remedies

Table 4: Drying defects and remedies

Drying defect	Prevention or remedy
Chemical stains	Place timber in drying stack as soon as it is sawn. Make sure that the conditions are good to promote air drying.
Sticker marking	Use dry stickers of an appropriate width for the timber being dried. End racking of susceptible timbers (sycamore and beech) for a period of time before they are piled.
Blue stain, mould, fungal decay	Place timber in stack immediately after sawing. Good air movement in the stack is necessary. Consider building the stack with flues. Make sure stack has an appropriate roof to prevent wetting. Green timber may need to be treated with appropriate anti-sapstain chemicals. Remove sawdust from surfaces
Insect attack	Trim bark from boards. Do not use infested stickers. Appropriate insecticides may be necessary.
End splitting	Use end sealants or plastic end cleats. Remove timber end cleats if attached. Stickers placed at the ends of the boards. Use timber shades if strong sunlight or warm winds are likely.
Surface checks	Check-prone species include oak, sycamore and beech. Modified stacks to retard air circulation can help to minimise checking. Wind baffles may be required on some sites.
Internal checking	May result from bottleneck checks that begin on the surface. Use same measures as for end splits and surface checks.
Distortion	Pile carefully with correct sticker spacing. Make sure stick thickness is uniform. Support the ends of all boards. Careful control on the uniformity of the thickness of the boards being cut can reduce distortion.
Cup	Differential shrinkage across the grain. Avoid flat sawn boards. Weights or adjustable strapping can minimise this defect.
Spring and bow	Differential shrinkage along the grain. Avoid drying low grade material with irregular grain, juvenile wood or reaction wood.
Twist	Avoid timber with spiral, interlocked or irregular grain.
Casehardening	Tension set in the outer zones is often found in rapidly dried timber. This can be relieved by subsequent kiln drying.

ii. Degrade characteristics of selected timbers

Experience has shown that certain timbers exhibit greater distortion and checking than others. While this will be dependent on a number of factors such as timber quality, accuracy of sawing and growth characteristics, the following shows the tendency for timbers to warp and check during drying.

Table 5: Distortion and checking tendencies of some timbers

Distortion tendency		
Low	Medium	High
Cherry	Ash	Beech
Walnut	Birch	Elm
Scots pine	Elm	Sycamore
Spruce	Oak	
	Fir	
	Larch	
	Hemlock	
Checking tendency		
Low	Medium	High
Cherry	Ash	Beech
Alder	Birch	Oak
Scots pine	Elm	Sycamore
Spruce	Walnut	Douglas fir
	Yew	Larch
	Fir	
	Hemlock	
	Hornbeam	

iii. Sawing tips to help drying

- If the speed of drying is important, do not saw timber any thicker than is necessary for the intended use.
- Sawdust on board surfaces can be minimised by correct sawing procedures and blade maintenance.
- Distortion such as cup and diamonding can be reduced by quarter sawing timber.
- Unless special sawing techniques are used, a majority of boards sawn from a log will be flat sawn. This should be taken into account, as shrinkage is greatest in the tangential direction. Shrinkage tables are available (see section 10) to calculate the amount of shrinkage that is likely to occur during drying.
- Quarter sawing tends to give lower volume recovery than flat sawing (through and through) but may yield higher seasoned recovery.
- Trimming the edges of through and through planks can reduce the time required for a plank to dry. There is no point drying material that will ultimately be discarded.

v. The economics of air drying

The costs of air-drying will vary considerably from one operation to the next. Some operators will be concerned with producing timber with minimal degrade while others will be more concerned about minimising drying times. There are many factors that should be considered when air drying timber such as the capital cost for establishing the yard, setting foundations,

manufacturing sticks, purchasing sleepers and roofing materials. The value of the land, the value of the timber and the current interest rate on capital must also be taken into account.

The Princes Risborough Laboratory devised a guide to the basic capital cost of air drying timber using the following equation

$$£/m^3 = \frac{t}{k}\left[(C + L + T)r + C(x + y)T(z)\right]$$

Where:
t = mean drying time in years
k = yard capacity in m³
C = capital cost of establishing a drying yard (including materials)
L = land value
T = value of timber held for drying
r = current interest rate (value/100)
x = depreciation (value/100)
y = maintenance (value/100)
z = insurance and office expense (value/100)

Here is a worked example based on a hypothetical situation

t = 12 months (1 years)
k = 50 m³
C = £200
L = £10000
T = £5000
r = 0.08
x = 0.2
y = 0.05
z = 0.02

Using the equation

$$£/m^3 = \frac{1}{50}\left[(200 + 10000 + 5000)0.08 + 200(0.2 + 0.05) + 5000(0.02)\right]$$

= 0.02(1216 + 50 + 100)

= £27.32 per m³

This estimated cost does not take into account the cost of labour or losses resulting from drying degrade.

The decision to dry timber will depend on a number of factors and in some cases it may not be economical, as it will not yield any higher profits. The price difference between green timber and air dried timber will vary considerably with species and demand. One saw miller contacted as part of this study indicated that he is currently offering green oak beams at £18.00 per cu.ft (£636 per m³) and air dried oak beams at £25.00 per cu.ft (£883 per m³).

vi. Drying wood for fuel

Some trees will not yield timber of a suitable grade. Nevertheless, the material produced can still be used for fuel wood. It is important to remember that wood burners only operate efficiently and with minimal emissions if the fuel wood has the correct moisture content (approximately 20 % moisture content).

Seasoning fuel wood requires some prior planning taking into account the same principles needed for drying more valuable timber. The following points may help to make the task easier:

- The fuel should be cut to fit into the firebox of the wood burner. Short lengths are easier to handle, stack and will dry faster.
- Unsplit logs may look appealing but generally make poor firewood. They also take longer to dry as the larger surfaces are covered in bark. Many domestic wood burning stoves require fuel with a maximum cross section dimension of 150mm.
- Fuel wood should be stacked to promote drying using the sun and the wind. Single rows of wood tend to dry faster than large piles. However, single row stacks can be unstable unless they are supported. Piling timber next to an open board fence rather than against a wall will promote air flow through the stack. The top tier of the stack can be covered to prevent wetting from the rain and the stack should not be in direct contact with the ground. Leave regular air spaces and sides of the stack open to increase air flow.
- When the wood is fully air dried it should be stored undercover prior to use.

9. Glossary

Air drying	A method of drying timber by exposure to natural atmospheric conditions. Air dried wood will attain a moisture content of approximately 14% to 20% depending on the climate.
Bound water	Water that is chemically bound to the cell wall constituents of wood.
Bow	Deviation of the face from being in a straight line along the length of a board.
Box piling	A stacking method for random length timber so that the length of the outside boards in each layer is equal to the full length of the stack.
Casehardening	A drying defect characterised by the presence of compression stresses in the outer zone and tensile stresses in the core. It occurs when rapid drying has caused permanent set of the outer zones of a piece of wood.
Check	A drying defect that occurs when tensile stresses cause the wood fibres to separate and form surface fissures.
Cleat	A timber, metal or plastic slat attached to the end of a piece of green timber to reduce moisture loss from the sawn end.
Cup	A form of distortion whereby there is a deviation from flatness across the width of the board.
Distortion (warping)	A drying defect that results in the timber caused by the differential shrinkage along the three axes of a piece of wood. Distortion may take the form of cup, bow, twist, spring or diamonding.
Drying defect	A characteristic developed during drying that may decrease the value of a piece of timber.
End sealing	A moisture resistant coating applied to the end grain surfaces of drying timber.
Equilibrium moisture content	The moisture content that a piece of wood will achieve when it is in equilibrium with temperature and relative humidity of the surrounding air.
Fibre saturation point	A theoretical point at which wood no longer contains any free water but still contains all its bound water.
Flue	A vertical space created in the centre of a drying stack to facilitate air circulation.
Free water	Water that is present in the cell cavities of wood.
Honeycombing	Internal checking or fibre separation usually along the rays.
Hygrometer	An instrument for measuring the humidity of air.
Hygroscopic	A material that loses and gains moisture as a result of changes in temperature and relative humidity.
Lift	Part of a timber stack that contains the same timber species or species with similar drying characteristics.
Moisture content	The total amount of water in a piece of wood. Usually expressed as a percentage of the oven dry weight.
Movement	The expansion and contraction that occurs with dried wood as its moisture content responds to changes in relative humidity in service.
Plain sawn timber	Timber converted so that the growth rings meet the face at an angle of less than 45º
Quarter sawn timber	Timber converted so the growth rings meet the face at an angle of not less than 45º
Reaction wood	Wood with distinctive characteristics that is formed in parts of

	leaning stems and branches.
Relative humidity	The amount of moisture in the air expressed as a percentage of the maximum moisture carrying capacity of the air.
Roof	A cover on top of a stack to protect the upper layers from exposure to the weather.
Sap stain	Stains formed in the sapwood usually caused by wood staining fungi or oxidation of living cell contents.
Shrinkage	The size reduction that occurs during drying. The extent of shrinkage will depend on the moisture content achieved during drying.
Split	A separation of the fibres that extends through the thickness of a piece.
Spring	Deviation of the edge from being in a straight line along the length of a board.
Stain	Discolouration in wood caused by micro-organisms, metals, chemicals or stickers.
Sticker	A strip of wood placed between layers of timber at right angles to the grain direction to provide air circulation in the stack.
Twist	Spiral distortion of a board.

10. Lists of useful contacts and references

Books

- The conversion and seasoning of wood by W.H. Brown ISBN 0-85442-037-1.
- Understanding Wood: A Craftman's Guide to Wood Technology by R. Bruce Hoadley ISBN 1561583588.
- Timber drying manual by G.H. Pratt. ISBN: 1860811248.
- Drying Oak Lumber by E. M. Wengert. Available from the University of Wisconsin-Madison, Department of Forest Ecology and Management, 1630 Linden Drive, Madison, WI 53706. USA.
- Opportunities for Dehumidification Drying of Hardwood Lumber by E. M. Wengert & others. Available from Virginia Forest Products Association, P.O. Box 160, Sandston, VA 23150. USA.
- Drying Hardwood Lumber by Joe Denig and others. Available from the Wood Education and Resource Center, 301 Hardwood Lane, Princeton, WV 247407513. USA.
- Quality Drying of Hardwood Lumber–Guidebook-Checklist by R. S. Boone. Available from the U. S Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53705-2398. USA.
- Softwood Drying by Larry Culpepper. Available from Miller Freeman Books, 600 Harrison Street, San Francisco, CA94107. USA.
- Quality Drying of Softwood Lumber–Guidebook-Checklist by M. Milota and others. Available from the U. S Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53705-2398. USA.
- Lumber Drying Sourcebook, 40 Years of Practical Experience edited by E. M. Wengert and R. Toennisson. Available from the Forest Products Society, 2801 Marshall Ct., Madison, WI 53705. USA.
- Air Drying of Lumber by the U.S. Forest Products Laboratory. Available from the Wood Education and Resource Center, 301 Hardwood Lane, Princeton, WV 247407513. USA.

Useful web sites on drying timber

- www.woodweb.com
- www.nt.gov.au/dpif/pubcat/newsletters/toppaddock/topjuly00_files/AirSeasoning.shtml
- http://sres.anu.edu.au/associated/fpt/drying/drying.html
- www.forests.qld.gov.au/library/tn39.pdf
- http://muextension.missouri.edu/xplor/agguides/forestry/g05507.htm
- http://www.ca.uky.edu/agc/pubs/for/for55/for55.htm

Solar kilns

- Solar heated timber drying kilns. Short information leaflet issued by TRADA Technology Ltd. Tel 01494 563091.
- Solar heated timber drying kilns by R.A. Plumptre and D.L. Jayonetti ISBN: 1900510006.
- Solar Heated Lumber Dry Kiln Designs by Eugene Wengert ISBN: 9991492917.
- www.woodweb.com/knowledge_base/Solar_Kiln_Designs_2.html
- www.ag.iastate.edu/departments/forestry/ext/pubs/F-303.pdf
- www.jonathan-guest.co.uk/solar-wood-kiln.htm
- www.execpc.com/timbergreen/page50.html
- www.choicetimber.com.au/solar1.htm

Dehumidifier dryers

- Arrowsmiths (Timber dryers) Ltd, Darlington, Co Durham. Information pack available Tel: 01325 481970.
- www.ebacusa.com/ld800.htm

Timber drying consultants

- Forest Products Research Centre, High Wycombe, Buckinghamshire. Tel. 01494 605103. E-mail: drying@fprc.co.uk. Contact: Paul Hodges.
- TRADA Technology Ltd, Hughenden Valley, Buckinghamshire. Tel. 01494 563091. Contact: Stephen Riddiough.
- Kiln Services Ltd, Burnham on Crouch, Essex.

Training courses that include timber drying

- Buckinghamshire Chilterns University College, High Wycombe, Buckinghamshire. Tel. 01494 522141. Contact: Paul Hodges
- Institute of Wood Science, Hughenden Valley, Buckinghamshire. Tel. 01494 563091.
- University College of North Wales. Tel 01248 382503. Contact: Martin Breese.

Kiln dryers

- Timber Drying Ltd, Barking, Essex. Tel. 020 594 7752.
- Sewstern Timber Services Ltd, Sewstern, Lincolnshire. Tel. 01476 861097.
- Timbmet Ltd, Cumnor Hill, Oxfordshire. Tel. 01865 862223.
- Charles Ransford & Sons Ltd, Bishops Castle, Shropshire. Tel. 01588 638331.
- Northwood Forestry & Sawmills, Pulborough, West Sussex. Tel. 01798 813029.
- Kiln Services Ltd, Burnham on Crouch, Essex. Tel. 01621 785935.
- A.J. Charlton & Sons, Frome, Somerset. Tel. 01373 812501.
- Brooks Bros (Danbury) Ltd, Chelmsford Essex. Tel. 01245 22696.

Calculating shrinkage of timber

- www.woodbin.com/calcs/shrinkulator.htm

Moisture meters and hygrometers

- Protimeter PLC, Marlow, Buckinghamshire Tel. 01628 474312.

Shade cloths

- Available from many garden centres and DIY stores.

Preservatives

- Osmose, Marlow, Buckinghamshire Tel.01628 486644.
- Arch Timber Protection, Castleford, Yorkshire Tel. 01977 671771.