COOPERATIVE EXTENSION SERVICE
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DRYING WOOD

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The wood in a living tree contains large quantities of water. After the tree is harvested, the weight of water in the wood is often greater than the weight of the wood itself. This water must be removed to some degree to make the wood usable. The process of water removal is called drying. The dried wood is then said to be seasoned.

This publication discusses the interaction of water and wood, reasons for drying wood, and the processes used to dry wood, both commercially and at home.

The total amount of water in a given piece of wood is called its moisture content (MC). Although we are accustomed to the fact that 100% signifies the total amount of something, the MC percent of wood can be greater than 100%. This occurs because the water can weigh more than the wood, and the MC of wood is usually based on the ratio of the weight of the water to the weight of the wood **after it has been dried** (*see Equation 1*).

Equation 1:

$$\% \text{ MC} = \frac{\text{weight of water in wood}}{\text{weight of ovendry (OD) wood}}$$

The general range of moisture content for **green** (undried) hardwood lumber can range between 45% and 150%. The standard method of determining the relationship of water in wood is to:

1) weigh a wood sample before drying to obtain the combined weight of the wood and water;

2) dry the wood sample in an oven at 103 $\pm 2°$ Centigrade (100°C = boiling point of water) for (approximately) 24 hours;

3) re-weigh the wood sample;

4) repeat steps 2 and 3 until the current weight equals the previous weight (the wood sample is now **ovendry** (OD), sometimes referred to as **bone dry**);

5) apply Equation 2 for determining % MC of the wood.

Equation 2:

$$\% \text{ MC} = \frac{\text{weight of wood before drying - OD weight}}{\text{OD weight}}$$

From the equation above, when the water weighs more than the wood, the % MC will be greater than 100. The OD weight is not a natural state for wood, and the sample must be weighed immediately after being removed from the oven. Because wood is a **hygroscopic** material (meaning that it readily takes up and retains moisture), it is impossible to prevent moisture from entering dry wood. As soon as the OD sample is exposed to the air, it will start to take in moisture from the air.

Why Dry Wood?

Some important reasons to dry wood include:

1) ***Better usability.*** Wood shrinks as it loses moisture and swells as it gains moisture. It should be dried to the % MC it will have during use.

2) ***Reduced shipping costs***. Dry wood weighs less (drying may reduce its weight by one-half or more). It is more profitable to transport wood than water.

3) ***Less likelihood of stain or decay*** during transit, storage, and use.

4) ***Reduced susceptibility to insect damage.***

5) ***Increased strength***. As wood dries below 30% MC, most strength properties increase.

6) ***Better "hold."*** Nails, screws, and glue hold better in seasoned wood.

7) ***Better finishing.*** Paints and finishes adhere better to seasoned wood.

8) ***Better heat insulation***. Dry wood is a better thermal insulator than wet wood.

9) ***Better preservation***. Dry wood must be used when treating with most wood preservatives.

10) ***Added value***. Drying the wood products before shipment adds value to the product.

How Dry?

Wood products should be dried to a final MC about mid-range of the expected MC of its surroundings. These can vary considerably by product, geographic location, and the intended use of the product (e.g., whether it will be used inside or outside).

Wood products used outside but protected from direct precipitation will stabilize with the surrounding environment at about 12% MC in the humid southern states, but may stabilize to as low as 6% MC in the arid Southwest. Hardwood furniture, all paneling, and other products used in heated buildings are estimated to stabilize at about 8% MC. Wood products to be used inside buildings that are only occasionally heated should be dried to about 18% MC.

Problems in Drying Wood

There are some negative aspects to drying wood, including:

1) *The great amount of energy that must be expended to drive the water out of wood.* As much as 80% of the total energy requirement for a sawmill can be used in the drying operations.

2) *The possibility of drying defects.* As wood dries, it shrinks in several dimensions. If wood is not correctly dried, the dimensional changes will cause drying defects, including **checks, splits, warp**, **casehardening**, and **honeycomb**. (These terms are defined in the *Glossary* at the end of the publication.)

Some explanation of these two items is warranted because of their importance in the wood drying process. Looking at the relationships between water and wood can help explain how wood dries.

Water and Wood

A commonly mistaken belief about lumber is that once dried it is permanently seasoned in its final dimension. A dry piece of wood will exchange water molecules with the surrounding air according to the level of atmospheric relative humidity. Loss or gain of moisture in wood products may cause such troublesome results as shrinking or swelling, interference with paint adhesion, and increased susceptibility to decay and stain.

Water is found in wood in three forms. **Free water** is found in its liquid state in the cell cavities or lumens of wood. **Water vapor** may also be present in the air within cell lumens. **Bound water** is found as a part of the cell wall materials. As wet wood dries, free water leaves the lumens before bound water. Water can be removed from wood fairly easily up to the point where wood reaches its **fiber saturation point** (FSP). The FSP is defined as that MC where the cell wall is completely saturated with (bound) water, but no liquid water is present in the cell lumens.

Wood **does not** start to shrink until it has dried below its FSP. FSP for most wood species falls in the range of 25 to 30% MC. It becomes increasingly hard to remove water from wood after reaching the FSP. Remember, it is only after water begins to leave the cell walls that the wood begins to shrink and its strength begins to increase.

How Wood Dries

Wood will seek an **equilibrium moisture content** (EMC) in relation to the relative humidity (RH) and temperature of its surroundings. That is, as wood is dried below its FSP, the amount of moisture leaving the wood will be determined by the relative humidity of the atmosphere surrounding the wood. Table 1 shows the EMC over a range of humidities. For wood to air dry, the moisture content of the air must be less than that of the wood.

Lumber drying is usually accomplished by evaporating the moisture from the surface of the wood. Wood dries "from the outside in"; that is, the surface of the wood must be drier than the interior if moisture is to be removed. Moisture will move from an area of higher moisture content to an area of lower moisture content within the wood. When the surface moisture evaporates from the sides or ends, moisture moves from the interior toward these locations. This process continues until the wood reaches its EMC. At this point the moisture content is equal throughout the piece of wood. Thicker lumber exposed to the same drying conditions will take longer to reach its EMC than thinner lumber.

Wood dries along the grain up to 15 times faster than across the grain. Therefore, a board will dry at a faster rate from its ends. However, because a board is usually many times longer than it is thick, most of the moisture loss occurs across the grain and out the surfaces of the piece. In other words, the moisture travels across the grain at a slower rate, but it has to cross a much shorter distance and, except near the ends of the board, it dries more through the surfaces.

The rate at which lumber dries is controlled both by the rate of evaporation from the surface and by the rate of movement of the water within the piece. As long as the moisture can move from the interior to the surface at a fast enough rate to keep the surface moist, the drying rate will be increased if the surface evaporation rate is increased. This can be accomplished by:

1) ***Increasing the air across the surface of the wood***. As long as the RH is low enough, the air will continue to dry all exposed surfaces of the wood.

2) ***Increasing the temperature of the air surrounding the wood.*** Warmer air holds more moisture; by increasing the temperature, the moisture-carrying ability of the air is increased.

3) ***Reducing the RH of the air.*** Water evaporates faster into the drier air.

Table 1. EMCs at Different Humidities for 30 to 90°F

RH	10	20	30	40	50	60	70	80	90
EMC	2-3	4	6	7-8	9-10	10-11	12-13	15-16	10-21

Lumber Stacking

Lumber, usually dried in stacks called piles, should be properly stacked for either air drying or kiln drying. Proper stacking will take advantage of wood's drying properties. The lumber stack should be uniform in length. If different lengths of lumber must be stacked together, the shorter pieces should be placed above the longer pieces. This prevents longer lumber from sticking out at the ends. Overhanging lumber is susceptible to breakage and warping. Shorter lengths of lumber may also be placed within the stack if both front and rear ends of the stack are kept flush.

Sticker Placement

Stickers, small uniform-sized boards, allow spaces for air to move across the lumber surfaces. They are used in stacks to separate the lumber so that air can move through the stack and to distribute the weight of the lumber vertically from top to bottom. They should be placed an equal distance across each layer of lumber and aligned on top of one another from the bottom of the stack to the top.

If the spaces between the lumber are not equal, air will flow more slowly through the larger spaces. Moisture on lumber surfaces at those locations will evaporate at a slower rate, and the lumber will dry more slowly. Stickers should be sufficiently more wide than thick so that they are not accidentally placed on edge between a layer of lumber.

There is no set sticker size, but the same size sticker should be used throughout a lumber stack. One inch by 3/4 inch or 1 1/4 inches by 1 inch are practical sizes for stickers.

Stickers should be placed as far apart as possible to ensure good air circulation. However, if stickers are placed **too far** apart, the lumber will not be supported well enough. Poor support while drying will cause the weight of the lumber in the upper layers to sag or otherwise distort the lumber near the bottom. Proper sticker distance is a function of the size (especially thickness) of the lumber. Generally, a sticker distance of about 24 to 36 inches should be sufficient for almost any size lumber. It is important that the stickers be placed at equal distances and straight across a layer and that each layer have a sticker at both ends for support. Proper sticker alignment allows air to circulate evenly across the surfaces of the lumber and allows a more uniform drying rate for each piece of lumber.

Commercial kiln operators need to consider a balance between more air flow across the lumber (thicker stickers) and more kiln capacity, that is, more layers (thinner stickers).

Air Drying

Air drying refers to stacking lumber and exposing it to the outdoors. Certain controls can be used in this stage of drying to make it more efficient. These include proper stacking, orientation and layout of the stack, and covering the stack.

The first level of control is proper stacking. Figure 1 shows a properly built stack of lumber for air drying. For this example, concrete blocks are used as a foundation, but treated timbers or used railroad ties could also be used. The stickers are uniform in size. The stickers are aligned one on top of the other and placed not more than 36" apart. The end of each board rests on a sticker. On the topmost layer of lumber, thicker and longer pieces are used to support a roof. In this case, 4 inch by 6 inch timbers are used. This lumber is 4 inches to 6 inches longer than the stickers.

A protective roof extends over the lumber stack by 2 to 3 inches on all sides. The roof protects the lumber from precipitation and direct sun. The roof may be slanted for precipitation to run off. Finally, some weight is needed to hold the roof in place. The extra weight will also help keep the top layer of lumber from warping as it dries. In this case additional concrete blocks are placed on the roof for added weight.

Another control is the orientation and layout of the stack(s) of lumber. Lumber stacked over a surface such as concrete or asphalt where water cannot pool will dry faster than that stacked over bare ground or ground covered with vegetation. As an example, black asphalt can significantly increase the rate of drying over that of vegetative-covered ground. A good rule is never to stack lumber over vegetative-covered ground since the bottom layer will always be exposed to air with a higher MC.

Shorter and narrower stacks of lumber will increase the drying rate. Stacking lumber away from buildings, trees, or other objects that can block the wind will increase the drying rate.

Wind is not needed to force air through the stack of lumber. Air circulation through the lumber can develop by natural **convection**. Warm, dry air enters the sides and top of the lumber stack. As the dry air moves over the lumber, it evaporates the moisture from the surfaces. Through the process of evaporation, the air becomes cooler, moister, and thus heavier. The heavier air moves toward the bottom of the stack. If the prevailing wind moves freely, the cool, moist air is blown away and replaced with warmer, drier air. Therefore, increasing the height of the foundation to allow more space under the pile will increase the drying rate.

Drying lumber **too fast** can cause drying defects. The most rapid drying will occur during the warmer, drier months. If drying defects occur, several things mentioned above can be reversed. The stack(s) of lumber can be built over concrete or bare ground rather than asphalt to slow the drying rate. Lumber stack(s) can be made larger (especially wider), or the wind can be partially blocked. All of these will slow the drying rate.

For lumber such as thick red oak that is difficult to dry without causing seasoning checks, several additional steps may be necessary. An **end-coating** material can be applied to the ends of the lumber. End-coatings are commonly made of a wax-base material that can be applied to the ends of boards to retard the excessive drying rates from these points. Burlap coverings can also be used to cover the ends of the lumber or to cover the entire stack of lumber. It is a common practice among commercial wood drying firms to use end-coatings, burlap, and other materials to impede the drying rate for certain species and sizes of lumber.

Final moisture content is determined by ambient air temperature, relative humidity, and drying time. Air drying wood can bring the MC down to a range of 20 to 30%. Depending on outside conditions and lumber species and size, air drying may take up to a year or more to obtain these moisture contents.

Drying Sheds

When large amounts of lumber are to be air-dried, pole-type sheds can be used to achieve greater control over the drying process. The sheds allow more control in that one or more sides can be blocked off, thus slowing the drying process.

Drying sheds can be very simple in their construction. They can become more complex by adding walls that can be raised or lowered and by adding a number of fans. Fans are used to accelerate the outside air through the building. Sides of the shed can be blocked and fans installed at one end. The other end of the shed is left open. Fans can be operated when increased circulation is desired and shut off for decreased circulation. For wood species that have a tendency to check when drying too fast, such as oak, fans should run when the exterior humidity is high and the air temperature is low. Fans can be turned off when the humidity is low and the temperature is high. This process slows the drying rate at the beginning when some species are susceptible to checking.

After the wood has been initially dried, the fans can be turned on when the temperature is high and the humidity is low. When the humidity is high, the fans are turned off to avoid reintroducing moisture into the lumber. Because no heat is added with this type of drying (sometimes referred to as **fan pre-dryers**), the final moisture content is determined by the ambient temperatures and relative humidity. As in air drying, the final MC range is usually 20 to 30%.

Kiln Drying

Drying wood in an insulated chamber and circulating air over it is called kiln drying. For most end uses of wood, all of the free water and much of the bound water should be removed. To accomplish this in a shorter period of time, or in more humid environments, a dry kiln must be used to dry the wood. Almost all commercially produced lumber is dried in a kiln before it is finally put in use.

Low-Temperature Dry Kilns

Pre-dryers

Commercial wood drying operations sometimes use a pre-dryer to dry green wood to a MC of around 25% before drying the wood to a lower moisture content in a dry kiln. Pre-dryers are usually referred to as a type of low temperature kiln. Temperatures typically range from 75 to 100°F, and relative humidities typically range from 60 to 90%. Pre-dryers have been used for more than 25 years in the northern latitudes of the United States where air drying conditions are unfavorable. More recently, pre-dryers have become established in other areas to shorten the air drying times of some hardwoods. Pre-dryers have controlled ventilation to regulate the drying rate. Other advantages of pre-drying over air drying are:

1) brighter lumber,
2) more uniform MC throughout the wood,
3) reduction in drying defects, and
4) one-third or more reduction in drying times.

Unless large amounts of lumber are to be dried, building, energy, and maintenance costs can make air drying a preference over a pre-dryer.

Dehumidification Dry Kiln

Dehumidifiers can be viewed as a type of low temperature wood dryer although temperatures can reach as high as 160°F. Dry kilns that operate at these temperatures are capable of drying most wood species at maximum drying rates. Dehumidification kilns can dry wood to a low MC of 5 or 6%. Dehumidification kilns operate in the following manner:

1) humidity (moisture in the kiln) is removed by condensation on the cold coils of a heat pump dehumidifier;
2) liquid Freon® is evaporated in the coils and then cools;
3) water is condensed from the moist air drawn across these evaporation coils;
4) the evaporated Freon® gas is compressed and the pressurized gas attains temperatures as high as 245°F;
5) dehumidified air is passed over the hot coils to provide useful energy for drying the lumber.

Vents are not needed in dehumidification kilns, as they are in steam kilns (see below). Vents can be used as an extra control, especially to help control temperatures in the drying cycle.

Solar Dry Kiln

In Kentucky, solar dry kilns offer a relatively inexpensive way for the woodworker or hobbyist to dry small quantities of wood. Drying times depend on the weather, and electricity is needed to run kiln fans. The heat energy necessary for drying comes from a solar collector. Depending on the chosen design, moist air can be removed through vents or condensed on the cold solar collector at night. Solar drying can result in high quality lumber, primarily because the moisture gradients in the lumber are allowed to equalize at night when drying is not taking place. Drying times vary and are relatively long.

In the United States, solar drying is not a commercially viable option due to the relatively long drying times. However, the United States Division of Agriculture Forest Service and others are conducting research in solar drying for Third World countries located in the tropics. Solar drying may be an inexpensive viable option for these countries to dry their woods before exporting them, and thus, add value to their economies.

Elevated Temperature Kiln

Steam Kiln Drying

In a steam dry kiln, fans are used to circulate air at speeds as high as 400 feet per minute (fpm). Drying temperatures can reach 180°F. Heat is supplied from an oil, gas, or wood waste-fired boiler.

Although drying the wood products before shipment adds value to the product and lowers transportation costs, it can also be one of the most expensive operations in terms of energy used. The ideal situation is for a wood products mill to use its own wood waste to fire a boiler for kiln operations, thus reducing fuel costs.

Temperature and humidity are carefully controlled during the drying cycle using **drying schedules** designed for the species, size, and condition of the wood. It is beyond the scope of this publication to discuss individual species and drying schedules. A good source of information for anyone wanting more detail can be found in the *Dry Kiln Operator's Manual*, available through the Superintendent of Documents, Washington, D.C.

Heated air is circulated over the wood, and the water on the wood surface evaporates, raising the humidity of the air. When the humidity of the air exceeds the level specified by the drying schedule, the warm, moist air is vented to the outside, and cool, drier air is brought in. Each time moist air is vented, all the energy from the boiler is also lost. The venting and reheating of the exchanged air consumes up to 80% of the energy required to dry lumber.

An example can illustrate why so much energy is required. A large kiln can hold more than 100,000 **board feet** of lumber. If the "wet" lumber weighs 4,700 pounds per thousand board feet (lb/mbf), and the dry lumber weighs 2,300 lb/mbf, then the water removed weighs 2,400 lb for every mbf of lumber. When drying 100,000 board feet of this lumber, the water removed weighs 240,000 lb. A gallon of water weighs about 8.3 lb. Almost 30,000 gallons of water had to be removed during the drying of this one load of lumber.

Stress Relief

As stated earlier, free water is removed from wood until the FSP is reached. After reaching FSP, the bound water starts to move to the surface of the wood. When this occurs, the wood cells start to deform, and the wood begins to shrink. The surface shrinks faster than the core, causing stresses in the wood. In addition, shrinkage occurs at different rates with regard to orientation of the grain. The difference in shrinkage can result in bow, crook, cup, or twist (see the *Glossary* for definitions of these terms).

When stresses are severe enough that checks occur on the wood surface, commercial operators **stress relieve** the lumber. This is typically done by rewetting the surface with wet steam for hardwoods such as oaks. In the case of faster drying hardwoods and most softwoods, water is used. In either case, the lumber surface will swell slightly, relieving the stress. For some end uses, such as construction lumber where appearances are not important, surface checks are not a problem. Sometimes kiln-dried lumber can absorb enough moisture when stored in a warehouse to remove stress.

High-temperature Dry Kilns

High-temperature dry kilns operate at temperatures of 200 to 240°F. Air velocities usually exceed 800 fpm. Vents are usually kept closed since control of the relative humidity is not essential.

This type of kiln was developed to dry softwoods. Commercial high-temperature kilns can dry large quantities of lumber in one day. However, only a few species of easily dried hardwoods can be dried in this fashion.

Other Designs

Small dehumidification and solar dry kilns are becoming more popular with home woodworkers. Wood hobbyists can find plans to build small dry kilns in their favorite trade journal. The Tennessee Valley Authority has developed a small dry kiln that gets its heat source from a wood-burning stove (Figure 2). The kiln will hold 2,200 board feet of 1" thick by 12' long lumber. Plans and information are available from TVA, Norris, Tennessee.

Several state universities and the USDA Forest Service Forest Products Laboratory have conducted research using small solar dry kilns. Results of the research and plans for the kilns are available from these sources. Companies, such as Wood-Mizer, sell small, relatively inexpensive dry kilns.

If you need further information regarding the drying of lumber or other wood products, contact your county agriculture Extension agent or a forestry or agricultural engineering specialist at the University of Kentucky.

GLOSSARY

Board foot - A unit of measurement for lumber and sawlogs represented by a board 12 inches long, 12 inches wide, and 1 inch thick or the cubic equivalent. In the wood products industry, the working unit is “1,000 board feet,” abbreviated *mbf*.

Bound water - Water in wood that is associated with the cell wall material. Wood does not shrink until after bound water starts to leave the cells.

Bow - A form of warp, bow describes a deviation flatwise from a straight line drawn from end to end of a board. If the board is laid flat, its shape starts to form a U.

Casehardening - A condition of varying degrees of stress set in wood such that the outer wood fibers are under compressive stress and the inner fibers under tensile stress. These stresses persist when the wood is uniformly dry and can cause warping when the wood is resawn or machined.

Checks - Lengthwise separation of wood fibers that extends across the annual growth rings. Commonly caused by stresses during drying. Surface checks occur on flat faces of lumber and end checks occur on the ends of lumber, logs, and other wood products.

Crook - A form of warp, crook describes a deviation edgewise from a straight line drawn from end to end of a board. If the board is laid on its edge, its shape starts to form a U.

Cup - A form of warp, cup describes a trough-like shape where the board edges remain approximately parallel to each other.

Equilibrium moisture content (*EMC*) - The balance of moisture content that wood attains at any given relative humidity and temperature of the surrounding atmosphere.

Fiber saturation point (*FSP*) - The stage in the drying or wetting of wood where the cell walls are saturated with (bound) water and the cell cavities are free of (liquid) water. Fiber saturation point for most wood species occurs at moisture contents of about 25 to 30%.

Free water - Liquid water in the cell cavities of wood.

Honeycombing - Checks, often not visible on the surface, that occur most often in the interior of the wood, usually along the wood rays.

Hygroscopic - Readily taking up and retaining moisture. Wood is a hygroscopic material. The forces between dry wood and water are so great that it is impossible to prevent the gain of moisture.

Kiln - A heated chamber for drying lumber, veneer, and other wood products in which temperature and relative humidity are controlled.

***Conventional-temperature* -** Type of kiln that typically operates with temperatures in the range of 110 to 180°F.

***Dehumidification* -** Type of kiln where the moisture is condensed out of the air which is reheated rather than vented to the outside.

***Elevated temperature* -** Type of kiln that typically operates with temperatures in the range of 110 to 211°F.

***High-temperature* -** Type of kiln that typically operates with temperatures above 212°F.

***Low-temperature* -** Type of kiln that typically operates with temperatures in the range of 85 to 120°F.

***Vacuum* -** Type of kiln where lumber is dried at less than atmospheric pressure either continuously or intermittently during the drying cycle.

Splits - Separation of wood fibers along the grain forming a crack or fissure. Splits may extend partially or completely through the wood.

Twist - A form of warp, twist describes a lengthwise “twisting” of a board in which one corner twists out of the plane of the other three.

Warp - Distortion in lumber and other wood products causing departure from its original plane. Common forms of warp are bow, crook, cup, and twist.

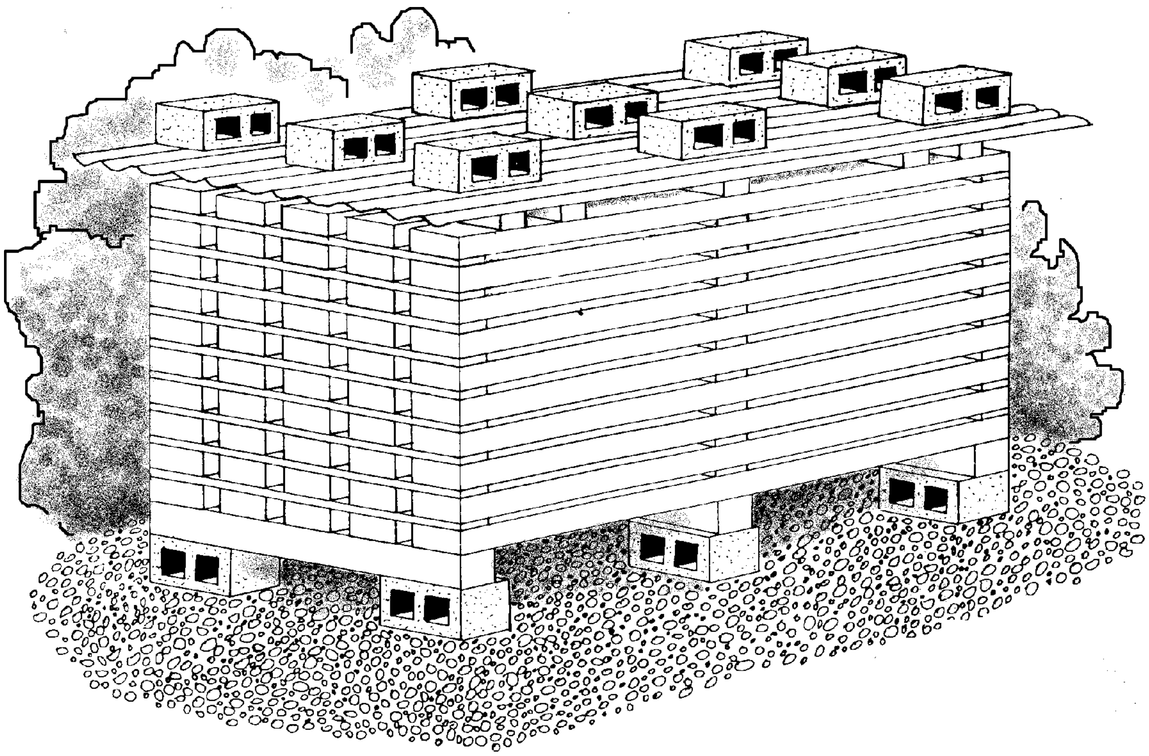

Figure 1. Example of a lumber stack with a concrete block foundation and correct sticker alignment. A roof protects the lumber from sun and weather.

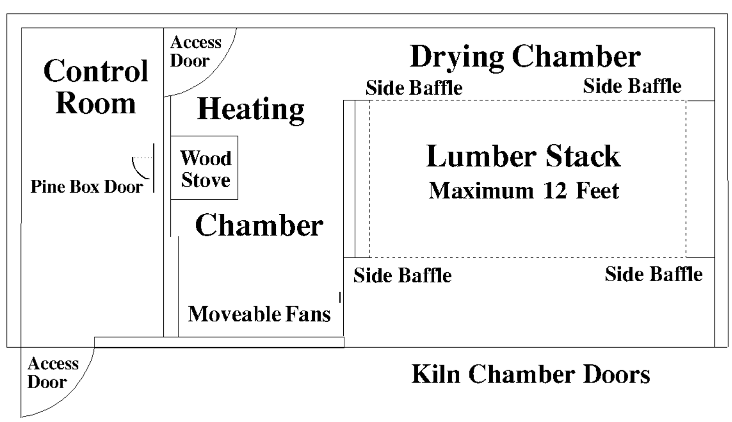

Figure 2. TVA's experimental dry kiln.

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