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Drying Characteristics of Three Selected Nigerian Indigenous Wood Species Using Solar Kiln Dryer and Air Drying Shed

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Abstract
Drying characteristics of three selected indigenous wood species were examined. Daily temperature and relative humidity in solar kiln and air dry shed were taken to determine the influence of the drying factors on the moisture content, density, volumetric shrinkage of *Alstonia boonei* (Ahun), *Ricinodendron heudelotii* (Erimado) and *Guarea cedrata* (Olofun) after drying for 41 days. Weights of the three wood species were taken at one day interval to determine percentage weight loss due to drying. *Guarea cedrata* had the lowest initial moisture content of 64.6 % and the highest density of 683 kg/m^3, *Alstonia boonei* had the medium density of 569 kg/m^3 and the initial moisture content of 82.26 % while *Ricinodendron heudelotii* had the lowest density of 324 kg/m^3 and highest initial moisture content of 368.5 %. *Ricinodendron heudelotii* had the highest volumetric shrinkage of 12.5 %, *Alstonia boonei* of volumetric shrinkage (9.7 %) and *Guarea cedrata* had the lowest value for the volumetric shrinkage (4.5 %) in the solar kiln. The densities of the three wood species were found to affect the drying characteristics of the wood. The temperature and relative humidity difference enhances the drying characteristic of the wood species inside the drying media.

1. Introduction

Wood is a hygroscopic material which will readily take up moisture and swell when exposed to a humid condition or expel moisture and shrink into a smaller dimension when subjected to a condition of lower humidity until equilibrium is reached. Hygroscopicity is one of the most distinctive properties of wood and wood product which enables it to absorb and desorb moisture from the surrounding air until it reaches equilibrium moisture content (EMC); a balance point between the wood's moisture content and that of the surrounding environment [1]. The fundamental reason for drying lumber is to enhance the properties of the wood and thereby make the lumber more valuable [2].The knowledge of dimensional stability property of a particular wood is important factor in reducing the incidence of undesirable 'movement' which could result in severe warping in finished product during service. The dimensional stability of wood can be enhanced through modification involving either the chemical treatment or reaction through heat treatment [3].

Wood drying refers to the process of reducing the moisture content of wood prior to its use. It is the process of removing its moisture to equilibrium with the conditions of the locality of use. Ideally, wood is dried to that equilibrium moisture content as will later (in service) be attained by the wood so that further dimensional change will be kept to a minimum. Drying wood enhances its strength properties, increases easy impregnation with preservatives, provides appropriate conditions for the chemical modification of wood and wood products; minimizes the decay, fungal infestation and insect attack. According to [4], nails, screws, and glue hold better in seasoned wood, minimizes other seasonal defects such as warping, bowing, cracks etc. after use, increases the electrical and thermal insulation properties of wood; makes easy and ensures better results in wood working, machining, finishing and gluing, paints and finishes last longer on dry wood.

Air drying involves exposing wood to the atmospheric condition. All the drying factors depend on the weather condition, hence, making the drying time of a given wood to be very long to achieve. In order to dry wood in an accelerated manner and to exact moisture content requirement, kiln drying becomes one of the most important processes for the efficient drying of green wood. The kiln process involves the drying of wood in a chamber where air circulation, relative humidity and temperature can be controlled so that the moisture content of wood can be reduced to a target point without having any drying defects. Kiln drying requires a comparatively large capital investment, but dries the wood in a short time and can provide dry timber for all seasons of the year whereas this is not possible in the case of air drying. A conventional kiln uses heat provided by either steam or hot water coils or a furnace to heat the kiln chamber and remove water from the wood [5].

The solar kiln is basically identical to the conventional kiln in its function except that the solar kiln relies on heat generated from sunlight which operates at a daily circle with its highest temperature and air speed in the kiln during the day while having a lower temperature level in the kiln during at night. Solar timber drying offers several advantages to those desiring an inexpensive means of drying small quantities of lumber [6]. The three wood species for this experiment were classified into high, medium and low density using the classification method by [7]. The classification showed *Guarea cedrata,* as high density wood, *Alstonia boonei* as medium density and *Ricinodendron heudelotii as* low density wood.

2. Materials and Methods

2.1. Study Area

The experimental solar kiln dryer and air-drying shed was set up at the Wood Workshop in the Department of Forestry and Wood Technology, Federal University of Technology, Akure, Ondo State, Nigeria, located on the longitude of 005.14796°E and latitude of 07.29311°N.

2.2. Materials Collection and Preparation

Freshly cut wood samples of *Alstonia boonei* (Ahun)*, Ricinodendron heudelotii* (Erimado) and *Guarea cedrata* (Olofun) were obtained from one of the sawmills in Akure, Ondo State, Nigeria. The wood samples were cut into sizes using circular sawing machine. The Solar kiln dryer at the wood drying experimental field was renovated using Aluminum sheet, nails, Evo-stic gum, Top bond glue, Insulator (Fiber glass), Hinges, Aluminum paint and Aluminum angle plate. Other materials include Hygro-thermometer, moisture meter, weighing balance and Vernier caliper. Samples from each wood species were cut into ten pieces of 25 mm × 75 mm × 450 mm. Five (5) samples from each of the wood species were placed inside the solar kiln dryer and Air drying shed.

2.3. Assessment of Variation in Temperature and Relative Humidity

Evaluation of solar kiln dryer and air dryer was carried out by taking the daily temperature and relative humidity readings in the solar kiln and air drying shed at 2 hours intervals using hygro-thermometer, the values obtained for temperature (°C) and RH (%) during the drying periods from 6am to 6pm were recorded.

2.4. Moisture Content Determination

Five samples of 20 mm × 20 mm × 60 mm were cut from each selected wood species to determine the initial moisture content. The wood samples were weighed on the weighing balance to know the initial weight and was transferred inside the oven to dry for 24 hours at a temperature of 103 ± 2°C. After oven dry, the wood samples were weighed again, to take the oven dry weight (W_o). The initial moisture content was determined using;

$$\text{M.C } (\%) = \frac{Wu - Wo}{Wo} \times 100$$

Where; Wu = green weight
W_o = dry weight

2.5. Determination of Wood Density

Five samples of 20 mm × 20 mm × 60 mm were cut from each wood species for density determination. After cutting, the wood samples were weighed to know the green weight and it was dried in the oven at 105°C for 24 hours until the weight was constant.

The densities of the three wood species were determined using;

$$\rho = \frac{m}{v}$$

Where; p = wood density
m = mass of the wood
v = volume of the wood

2.6. Drying Processes for the Selected Wood Species

The drying rate was evaluated for the periods by taking the green weight of ten wood samples of 25 mm × 75 mm × 450 mm cut from each of the three wood species. Thereafter, the solar kiln and the air dryer were loaded with five samples for each of the wood species. Weight loss due to drying was taken every other day using weighing balance until a constant weight was obtained. The result was validated by taking the final weight and oven dry for 24 hours to determine the final moisture content using:

$$MC\% = 100\left[\frac{T_1 - T_f}{T_f}\right]$$

Where:
MC = moisture content,
T_1 =weight of the timber at constant reading,
T_f= oven dry weight of the wood after constant reading.

2.7. Determination of Volumetric Shrinkage of Three Selected Wood Species

The volume of the wood samples was taken at the initial stage and also at the end of the drying periods to determine the volumetric shrinkage. The initial volumes of the samples in both drying media were taken at initial stage using the Vernier caliper. At the end of the drying process, the final volume attained was measured. The volumetric shrinkage of the samples was estimated using:

$$VS(\%) = 100\left[\frac{D_\circ - D_i}{D_\circ}\right]$$

Where; VS = volumetric Shrinkage
D_o = wet volume
Di = dry volume

2.8. Experimental Design

The experimental design that was used for this research was 2 × 3 factorial experiment in Completely Randomized Complete Block Design (RCBD). Data collected in this study were processed using excel spreadsheet and analyzed using Statistical Package for Social Sciences(SPSS) to determine the significant difference in the moisture content achieved by the two drying methods and the wood species.

3. Results and Discussions

3.1. Mean Temperature of the Solar Kiln and the Air-Drying Shed

The mean daily temperature for solar kiln and air-drying shed were presented in Figure 1. This study started at early period of rainy season on the 5th of April, 2013 and terminated on the 15th of May, 2013. The mean temperature in the solar kiln increased from 31°C to 48°C while the mean temperature in the air drying shed increased from 24°C to 31°C. Temperature was observed to be highest at some periods of the day in both solar kiln and air drying shed. In the solar kiln, highest mean temperature ranged from 49°C to 58°C between 12 noon and 2 pm but falls gradually from 2 pm. The air drying shed attained its maximum temperature of 32°C at about 2 pm and falls gradually thereafter. This variation in the mean temperature for solar kiln and air-drying shed showed that solar kiln conserved the heat and also better heat retention compared air-drying shed.

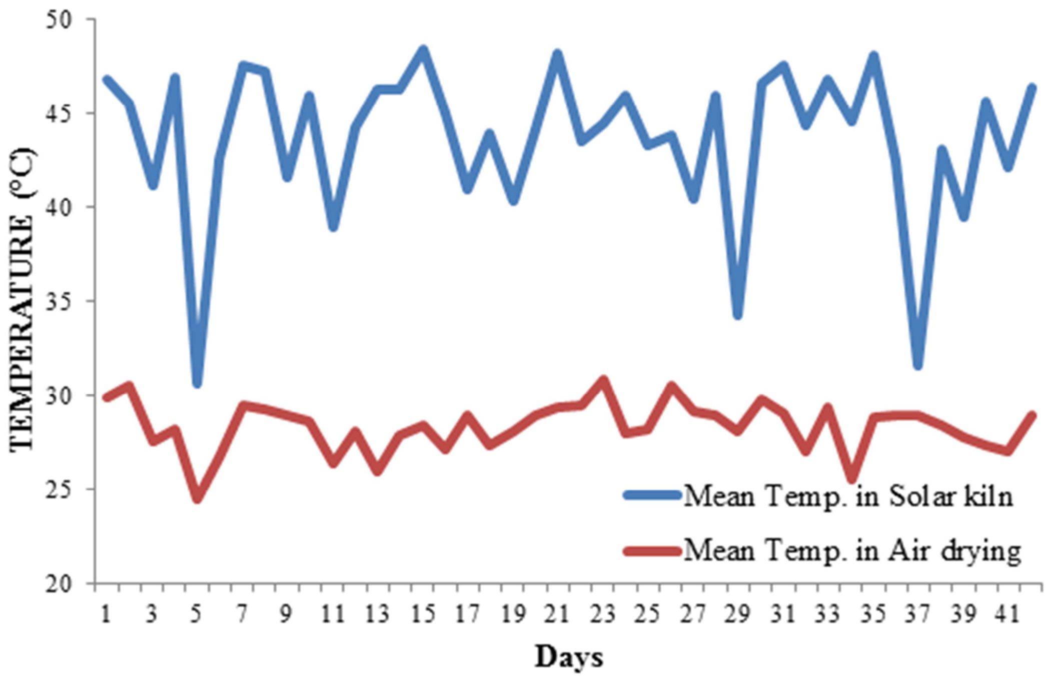

Figure 1. *Daily mean Temperature for Solar Kiln and Air Drying Shed.*

3.2. Mean Relative Humidity of the Solar Kiln and the Air-Drying Shed

The result of mean relative humidity (RH) observed in the solar kiln and air-drying were presented in figure 2. Throughout the drying period, a minimum of 60 % RH and maximum of 85 % RH was observed in the air-drying shed while a minimum of 42 % and maximum of 78 % RH was observed in the solar kiln. RH was at the minimum of 33 % and 52 % in the solar kiln and air-drying shed respectively at 2 pm after which it increased gradually toward the end of the day. It could be observed that solar kiln attained a higher temperature and lower relative humidity than the air-drying shed which enhance the rate of drying of the wood in the solar kiln dryer.

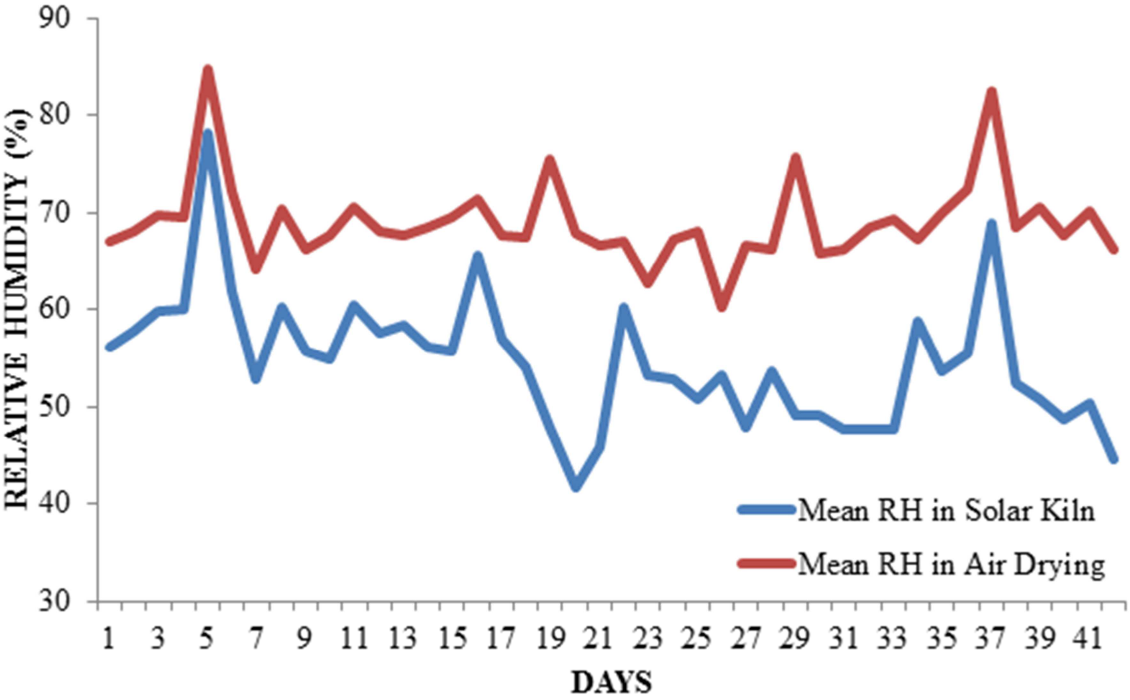

Figure 2. *Daily Mean Relative Humidity for Solar Kiln and Air Drying Shed.*

3.3. Difference in Moisture Loss in the Three Wood Species in the Solar Kiln and Air Drying Shed

The patterns of moisture loss in the three wood species for both solar kiln system and air drying shed are presented in Figures 3 and 4. Despite its high initial moisture content, *Ricinodendron heudelotti* dried to the same moisture content with *Alstonia boonei* and *Guarea cedrata* within a short time because of its low density and the same environment of drying. This may be as a result of low complexity of the cell structures i.e. absence of vessel which can make drying to be slower. This corresponds with the work of [8], which specified that the structural composition of different wood species is the reason for different seasoning period. *Rinodendron heudelotti* contain high moisture contents due to its low density. Low density woods contain more pores or void space in its wood cell, thereby leaving more space for water to occupy the wood. The high porosity of the wood accounted for high initial moisture content in *Rinodendron heudelotti*. *Alstonia boonei* contain a lower moisture content compared with *Guarea cedrata* but their moisture content was not far from each other because they contain more of woody tissues with little space for water. This resulted to a similar drying rate for both *Alstonia boonei* and *Guarea cedrata*. The three wood species reached the same moisture content on the thirteen (13) day of drying in the solar kiln and on the nineteen day (19) in the air drying shed. This may be as a result of exchange of moisture content among the wood species. Wood is hygroscopic material that has the tendency to absorb and desorbs moisture. *Alstonia boonei* and *Guarea cedrata* dried faster due to low moisture content and they may have absorbed the excess moisture content released by *Ricinodendron heudelotti*, making the three wood species to reach the same moisture content on the thirteen (13) and nineteen (19) day, respectively. Wood density may be an important factor for selecting wood for drying process. This scenario may be advantageous in an abnormal drying condition where the wood cell wall dries faster than the cell lumen. This abnormal situation can lead to different drying defects but the excess moisture transfer from other wood species can help to prevent such wood defects. The similarity shown on thirteen (13) and nineteen (19) day of drying may also be as a result of sawing in the same direction. The sawn wood, from which the wood samples were cut, was sawed using through and through cutting. Through and through cutting made all the wood samples to be in a longitudinal direction. Longitudinal direction has the same properties in term of shrinkage and swelling, thereby making the rate of drying to behave the same way.

The direction of the wood may also be another important factor to be considered in the wood drying process. The moisture content of the three wood species increases between thirty seven (37) and forty one (41) in the solar kiln and a slight increased in air drying samples during the same periods of drying. These sudden increased may be due to increase in the relative humidity of the solar kiln system during this periods as showed in figure 2, thereby making the cell wall of the three wood species to absorb moisture which brought about the moisture content increased. The moisture content reduced after the relative humidity reduced. This corresponds with the work by [9], which found out that relative humidity is an important factor in the rate of wood drying.

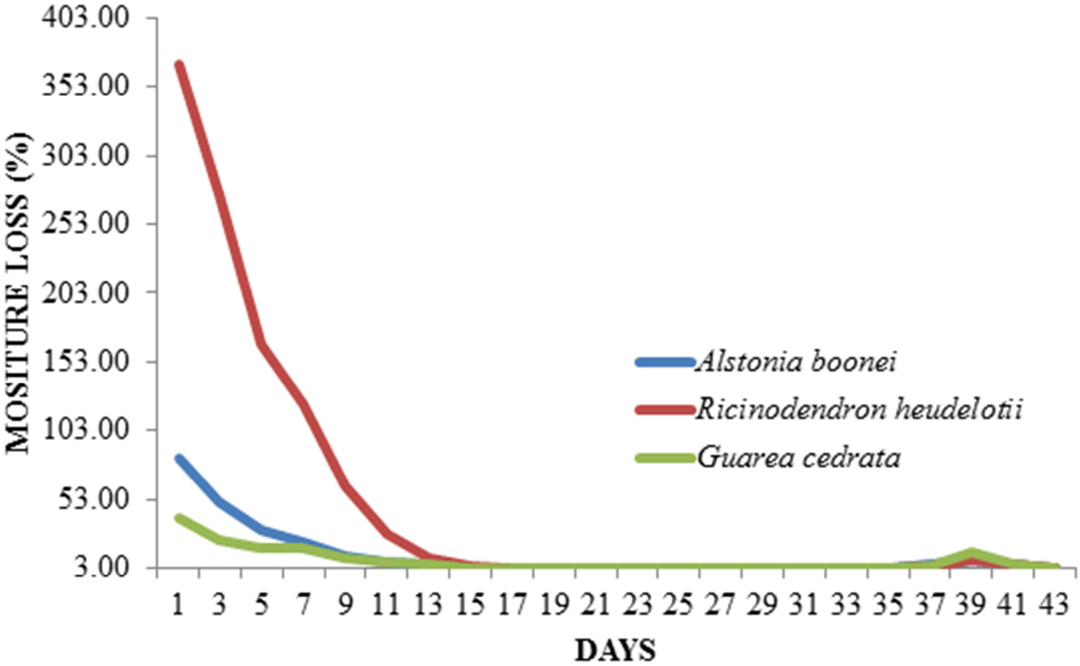

Figure 3. *Moisture Loss in the Three Wood Species for Solar Kiln.*

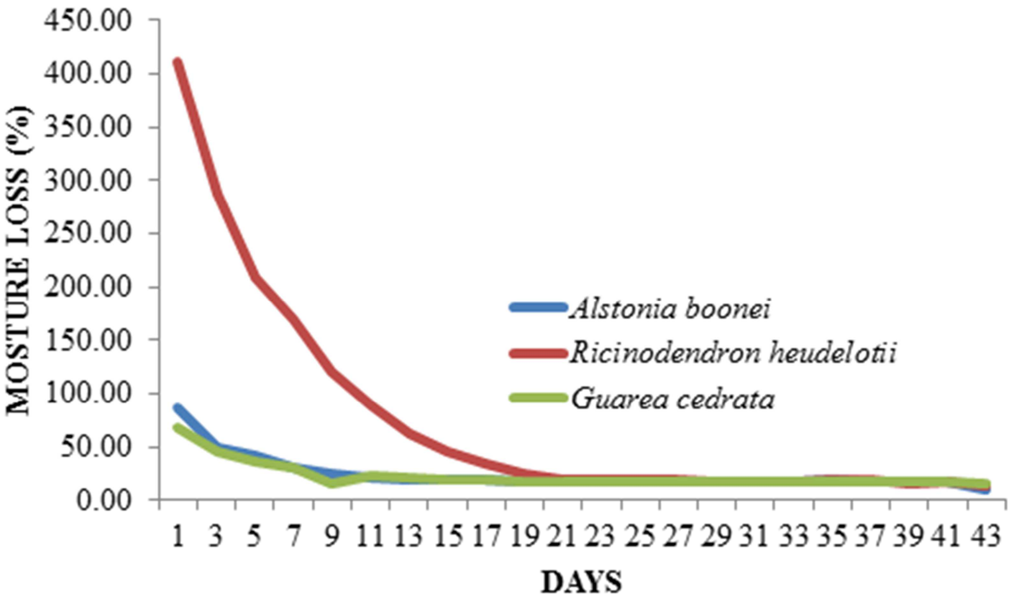

Figure 4. *Moisture Loss in the Three Wood Species for Air Drying Shed.*

3.4. Effect of Wood Species and Drying Media on the Final Moisture Content

The final attainable moisture content of the three wood species in the two media is shown in the Table 1. The overall final moisture content attained after 41 days by *Alstonia boonei*, *Ricinodendron heudelotii*, and *Guarea cedrata* were 6.46 %, 8.97 %, and 9.55 %, respectively. The final moisture content attained in the solar kiln and air-drying shed were 3.73 % and 13.28 %, respectively. There is a significant difference in the overall final moisture content attained by the species and through the drying media. The variation in the moisture content attained by the species could be as a result of properties of the individual wood species. Wood samples dried in the solar kiln were able to attain lower moisture content compared to the samples in the air-drying shed. The rate of drying to lower moisture content in the solar kiln may be accounted for by high temperature, low relative humidity and air flow in the solar kiln. [10] and [4] agrees to the fact that temperature influences the drying rate by increasing the moisture holding capacity of air, as well as accelerating the rate of diffusion of moisture within the wood cells, lower relative humidity enhances higher drying rates and air flow improves the movement of water vapour from the surface of the wood. Wood species dried in the solar were able to attain constant moisture content of 2.8 % after 13 days while samples in the air-drying shed species attained 17.78 % moisture content at 19 days of drying. Wood samples in the solar kiln dried faster than those in the air drying shed. This implies that a solar kiln system is more effective for wood drying than the air drying shed. This agrees with the previous work by [11], which examined the performance of solar kiln dryer.

Table 1. *Mean of final moisture content after the drying period.*

Source of Variation		Mean Final Moisture Content (%)
Species	*Alstonia boonei*	6.46 ± 1.44^a
	Ricinodendron heudelotii	8.97 ± 1.89^b
	Guarea cedrata	9.55 ± 2.09^b
Drying Media	Solar	3.73 ± 0.08^a
	Air dryer	13.28 ± 1.02^b

Means with different letters are significantly different ($P^< 0.05$)

3.5. Effect of Drying Media on the Volumetric Shrinkage of the Wood Species

Table 2. *Mean volumetric shrinkage of wood species after the drying period.*

Source of Variation		Mean Volumetric shrinkage (%)
Wood species	*Alstonia boonei*	8.56 ± 0.68^b
	Ricinodendron heudelotii	9.84 ± 1.10^b
	Guarea cedrata	3.58 ± 0.88^a
Drying Media	Solar	8.92 ± 1.08^b
	Air dryer	5.73 ± 0.76^a

Means with different letters are significantly different ($P^< 0.05$)

The overall mean volumetric shrinkage of the wood species is shown in Table 2. Shrinkage values observed in *Alstonia boonei, Ricinodendron heudelotii* and *Guarea cedrata* were 8.56 %, 9.84 % and 3.58 %, respectively. Result of shrinkage values in the drying media also revealed that solar kiln and air-drying shed had a mean volumetric shrinkage of 8.92 % and 5.73 %, respectively. There were significant differences in the volumetric shrinkage among the wood species and between the drying media used. The higher shrinkage value in the solar kiln was as a result of high rate of stresses set up due to high temperature observed in the solar kiln. Although, no physical degrade was observed on the wood samples, result indicate that the rate at which the dried samples shrank was higher compared to the samples dried in the air-drying shed.

4. Conclusions

Drying is an indispensable stage of wood processing which ultimately affects the quality of the wood and its properties. Wood properties varies from one species to another, this contributes to differences in their drying characteristics when exposed to a particular drying phenomenon. Drying wood to equilibrium moisture content of its environment improves the quality and also enhances its durability in service. Different factors like wood density, direction of cut and heating capacity of the system should be considered in selecting wood for a particular drying system. In addition to the factors mentioned above, the wood thickness must also be considered in selection for drying in the same chamber. Wood species of different properties varies in their rate of drying and hence, the reason to avoid drying them in the same chamber. To attain lower moisture content within a very short period of time, solar kiln can be used as proved by the results obtained.

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