WOOD PRODUCTS NOTES

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Summary: Lumber is often air-dried for months prior to being kiln dried. The air-drying yard manager must decide when to end air-drying and move the lumber to the dry kiln.

This issue of Wood Products Notes presents the Air-Drying Estimator Excel spreadsheet which is based on previous air-drying of lumber research. The intent of the program is to help the air-drying yard manager estimate how long to air-dry lumber prior to kiln drying based on species group, U.S. location, the start date, initial moisture content, and the target or ending moisture content. The Air-Drying Estimator will estimate the date the lumber dries to the target moisture content, the number of air-drying days required for the base case and for lumber placed on the yard each month, and displays drying curves.

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Using the Air-Drying Estimator to Predict the Air-Drying Time for Lumber

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Introduction

For many applications, hardwood lumber must be dried prior to use. Because some species (such as oak) must be dried slowly, using a limited resource such as a dry kiln is too time consuming and would result in low productivity of dried lumber. As a result, air-drying is typically employed prior to kiln drying for many slow drying species.

As Denig *et al*. point out (2000), the air-drying process is incorrectly thought to be efficient and cost effective. First, air-drying time for some locations and seasons are simply too long and hence costly to be either efficient or cost effective. Secondly, air-drying beyond about 28% moisture content (MC) usually increases degrade. When these two facts are coupled with the knowledge that most drying degrade begins during the early stages of drying, the importance of being able to model the rate of moisture loss during air-drying becomes evident. The problem is complicated by the fact that the rate of air-drying for lumber varies based on geographic location and the time of year.

Air-Drying Models

There have been studies to estimate air-drying times for lumber. Denig and Wengert (1982) published an air-drying calendar for red oak and yellow poplar 4/4 lumber drying in the Roanoke, VA area based on weather data and measured moisture loss. The equations developed predicted daily MC loss and included the variables of average daily temperature and relative humidity and the average daily moisture content. Other weather variables such as wind speed and precipitation were not found to be significant. The resulting models that they found to best describe the air-drying process were as follows:

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For 4/4 red oak:

$$\text{MC Loss} = 0.27 + 0.00071(\text{MC}^2) + 0.025(^{O}\text{F}) - 0.031(\text{RH}) \quad [1]$$

For 4/4 yellow poplar:

$$\text{MC Loss} = -2.00 + 0.153(\text{MC}) + 0.056(^{O}\text{F}) - 0.062\ (\text{RH}) \quad [2]$$

Simpson (2004) developed a nonlinear regression equation to describe air-drying for two hardwood species. Regression coefficients were developed to predict the daily MC loss based on the moisture content at the start of the day and the average daily temperature and relative humidity. Equations were developed for 4/4 northern red oak air-dried in Madison, WI, and for 4/4 sugar maple that was air-dried in upper Michigan. The resulting models for air-drying were:

For 4/4 northern red oak:

$$\text{MC Loss} = (\text{MC})^{2.38} \times (^{O}\text{F})^{0.759} \times (\text{RH})^{-2.91} \quad [3]$$

For 4/4 sugar maple:

$$\text{MC Loss} = (\text{MC})^{2.18} \times (^{O}\text{F})^{1.89} \times (\text{RH})^{-3.57} \quad [4]$$

Overview of the Air-Drying Estimator Excel Model

To be useful to the air-drying yard manager, the required input data for the air-drying model must be readily available and not extensive. These two previously mentioned studies produced four equations that can predict daily moisture loss based on wood moisture content at the start of the day and the average daily temperature and average daily relative humidity. Hence, they can be used to develop moisture content curves over time if the local weather data is available. Climate Normals for the period 1981 – 2010 (NCDC, 2016) were recently used to calculate the monthly EMC for 252 locations in the United States (Mitchell, 2016). With the mean monthly weather data available from the Climate Normals, the Air-Drying Estimator Excel model was developed that can be used to calculate and display drying curves for four species groups using the above air-drying models.

The Air-Drying Estimator can be used to develop moisture content curves over time and estimate the length of time to dry to a target moisture content for red oak, yellow poplar, and sugar maple, for 252 locations in the United States. The spreadsheet model was designed to be easy to use. The model estimates of air-drying time will be useful to air-drying managers and help them determine when to move air-dried lumber into the dry kiln.

Application of the Air-drying Estimator Excel Model

The Air-drying Estimator Excel model is simple to use. The program requires just five pieces of information from the user:

- Species Group Selection – species selection of the lumber being air-dried. The choices are:
  - Red Oak Group V1 – red oak (*Quercus spp*.), Denig and Wengert (1982)
  - Red Oak Group V2 – northern red oak (*Quercus rubra*), Simpson (2004)
  - Sugar Maple Group – sugar maple (*Acer saccharum*), Simpson (2004)
  - Yellow Poplar Group – yellow poplar (*Liriodendron tulipifera*), Denig and Wengert (1982)
- Location – selection of the geographic location of interest (choice of 252 U.S. locations):
- Start Date – the date that air-drying begins:
- Start Moisture Content – the actual or estimated initial moisture content of the lumber:

- Target Ending MC – the planned lumber moisture content at which lumber will be removed from the air-drying yard and placed in the dry kiln.

The program output immediately displays the following estimates:
- End Date – the estimated date when the lumber will reach the Target Ending MC;
- Air-drying Days - The number of air-drying days to reach the Target Ending MC;
- Average Annual Drying Days - The average number of drying days assuming drying started on the 1st of each month for the entire year;
- Drying curve displaying moisture content vs. air drying days based on user input for the species, location, start date, and initial moisture content;
- Comparison of drying curves for each month based on user input for the species, location, and initial moisture content;
- Histogram comparing the number of air-drying days required for lumber started drying on the 1st of each month.

WOOD SPECIES GROUPS

It is useful to extend the application of the Air Drying Estimator spreadsheet beyond the limited species groups modeled. The suggested grouping of species in Table 1 is based on similar average number of air drying days (Denig *et al*., 2000). [Note that Simpson's work was done with sugar maple (Acer saccharum) and northern red oak (Quercus rubra). Denig's work was with yellow poplar (Liriodendron tulipifera and unspecified red oak (Quercus spp.).]

Table 1. Suggested grouping of species for the four drying groups modeled in the Air Drying Estimator.

Red Oak Group V1	**Sugar Maple Group**
Oak, red (lowland)	Ash
Oak, Southern red	Beech, American
	Cherry
	Walnut, black
Red Oak Group V2	**Yellow Poplar Group**
Oak, red (upland)	Basswood, American
Oak, Northern red	Butternut
Oak, white	Cottonwood, eastern
Hickory	Elm, American, slippery
Pecan	Hackberry, sugarberry
Elm, rock, cedar, winged	Maple, red, silver
Sweetgum, heartwood (red gum)	Sweetgum, sapwood (sap gum)
	Sycamore
	Willow, black

EXAMPLE USE OF THE AIR-DRYING ESTIMATOR

An example will illustrate the use of the Air-Drying Estimator Excel spreadsheet. Assume that we want to estimate the air-drying time required for 4/4 red oak in the Charlotte, NC area. Air-drying to a target ending MC of 28% will commence on June 1 and we estimate that the starting MC is 80%. Table 2 illustrates the User Input table from the spreadsheet. Note that the Species Group Selection and Location entries are selected from drop down lists. The Start Date, Start Moisture Content, and Target Ending MC are entered by the user directly into the spreadsheet cell.

Table 2. Example of User Input information required for Air-Drying Estimator.

User Input

Species Group Selection	4/4 Red Oak Group V1
Location	NC CHARLOTTE
Start Date	6/1/2016
Start Moisture Content	80
Target Ending MC	28

The Program Output consists of three pieces of information (Table 3) and three graphs (Figure 1). The program estimates the End Date, that is, the approximate date the lumber is expected to reach the Target Ending MC on the air-drying yard. The number of Air-Drying Days to the Target MC is also given. Also provided is the Average Annual Drying Days throughout the year, assuming similar batches of lumber were started on the 1st of each month.

Table 3. Example of output table provided by Air-Drying Estimator.

Program Output

End Date	7/2/2016
Air Drying Days to 28 % MC	31
Average Annual Drying Days	66

Results are also presented in three graphs generated by the Air-Drying Estimator spreadsheet. As shown in Figure 1 these are: A) the drying curve for the air-drying case entered by the user; B) the drying curves for each month if drying began on the 1st of each month, and; C) the histogram of the total number of days required for air-drying to the Target Ending MC when drying starts on the 1st of each month.

With the Red Oak Group V1 and Yellow Poplar species groups, there are some situations when air-drying commences near the start of the slow drying months, the model predicts that moisture loss may appear to cease for a period of many days or even months (or even result in moisture gain). These two species groups are from Denig and Wengert (1982) who pointed out that given the form of the model equation moisture gains may result with the use of low temperature and low initial moisture content, and recommended that the moisture loss be considered zero. As shown in Figure 1B, this occurs for 4/4 red oak lumber that begins air drying in Charlotte on October 1 and appears to cease drying (and begins to gain moisture) near the end of November. When this scenario is entered into the Air-Drying Estimator, the output (Table 4) indicates that it will take 163 days to reach the Target End MC of 28% on March 13. A warning notice is given to the user, however, that effective air-drying ceases on November 30 at a moisture content of 29.3% (Table 4).

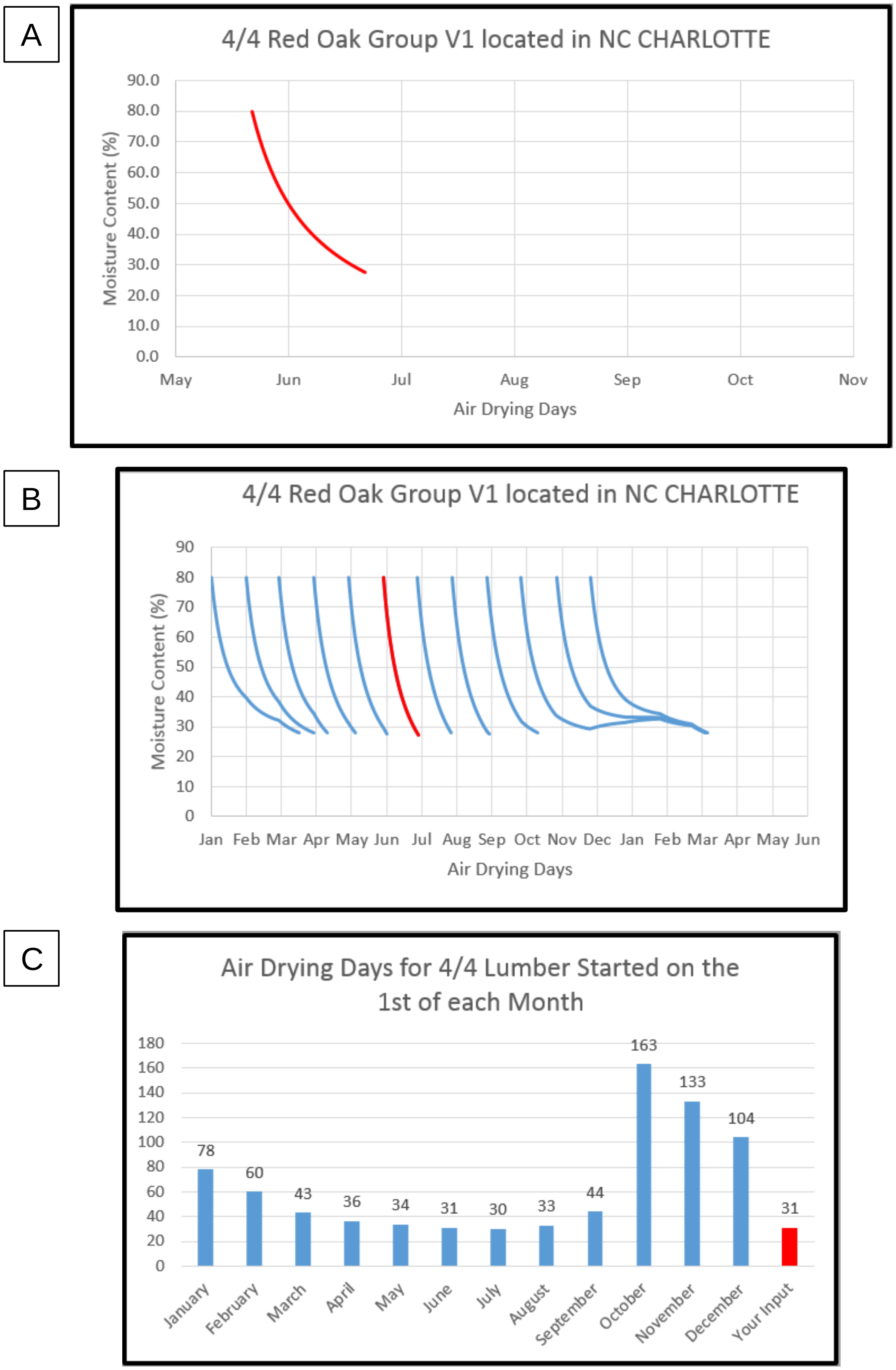

Figure 1. Output graphs from the Air-Drying Estimator: A) the drying curve for the air-drying case entered by the user; B) the drying curves for each month if drying begins on the 1st of each month, and; C) the histogram of the total number of days required for air-drying to the Target Ending MC when drying starts on the 1st of each month.

Table 4. Example of Air-Drying Estimator output table and the warning notice that effective air-drying has stopped prior to reaching the Target Ending MC.

Program Output

End Date	3/13/2017
Air Drying Days to 28 % MC	163
Average Annual Drying Days	66

Notice: Average weather suggests effective air drying will cease on 11/30 at about 29.3 percent moisture content !

Known causes of Inaccuracies

The results of the Air-Drying Estimator spreadsheet only provide an estimate of the air-drying time required and are not expected to be exact. The development of the Air-Drying Estimator took liberties in applying previously developed models, compromising between the user's need for useful information and the model's need for input data. For example, the four model equations were developed based on daily weather and wood moisture content data, but the Air-Drying Estimator uses average monthly weather data to calculate daily moisture loss. In addition to this lack of precision, the monthly averages employed by the Air-Drying Estimator likely does not reflect a particular year's weather. The Air-Drying Estimator allows the user to employ equations to geographic locations far away from where they were developed, and that might introduce significant errors. The species groupings are a "best guess" based on other published works, and it is assumed that Denig's red oak likely included a large amount of lowland and southern red oak.

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