Mejores Practicas para el Secado de Madera: Construcción y Operación de un Horno Solar

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Auspiciadores

- A wood products laboratory and outreach facility to support sustainable community forestry in Puerto Rico (Z-358, EEA-UPR; USDA-National Institute of Food and Agriculture Award No. 2020-70004-32469)
- Best management practices for forested lands in Puerto Rico: A review and compendium (Z-336, EEA-UPR, USDA-Forest Service International Institute of Tropical Forestry)

Contenido

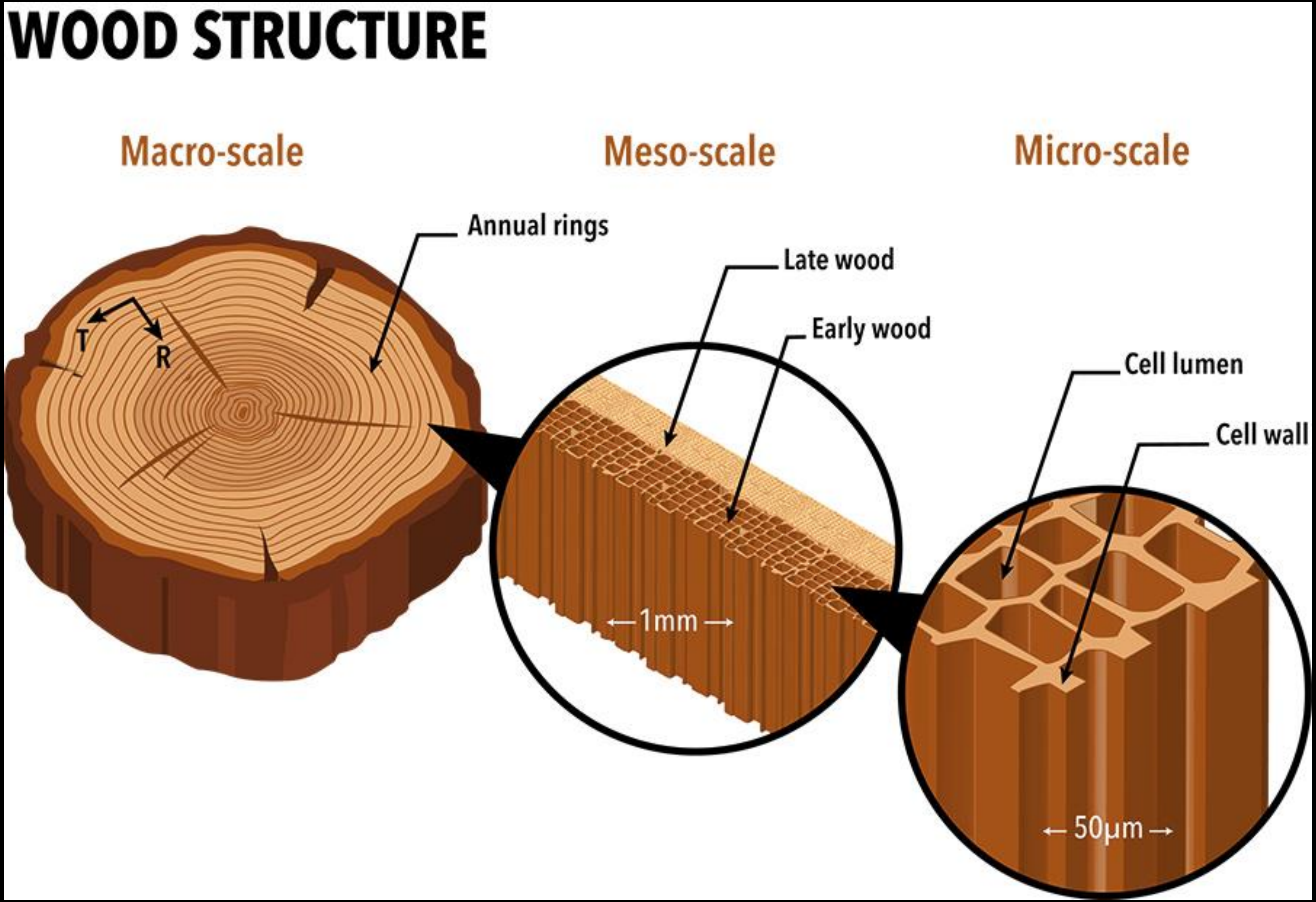
- Resumen fisiológico
- Contenido de humedad
- Defectos
- Métodos para el secado
- Construcción y operación de un horno solar

Objetivo del secado de madera

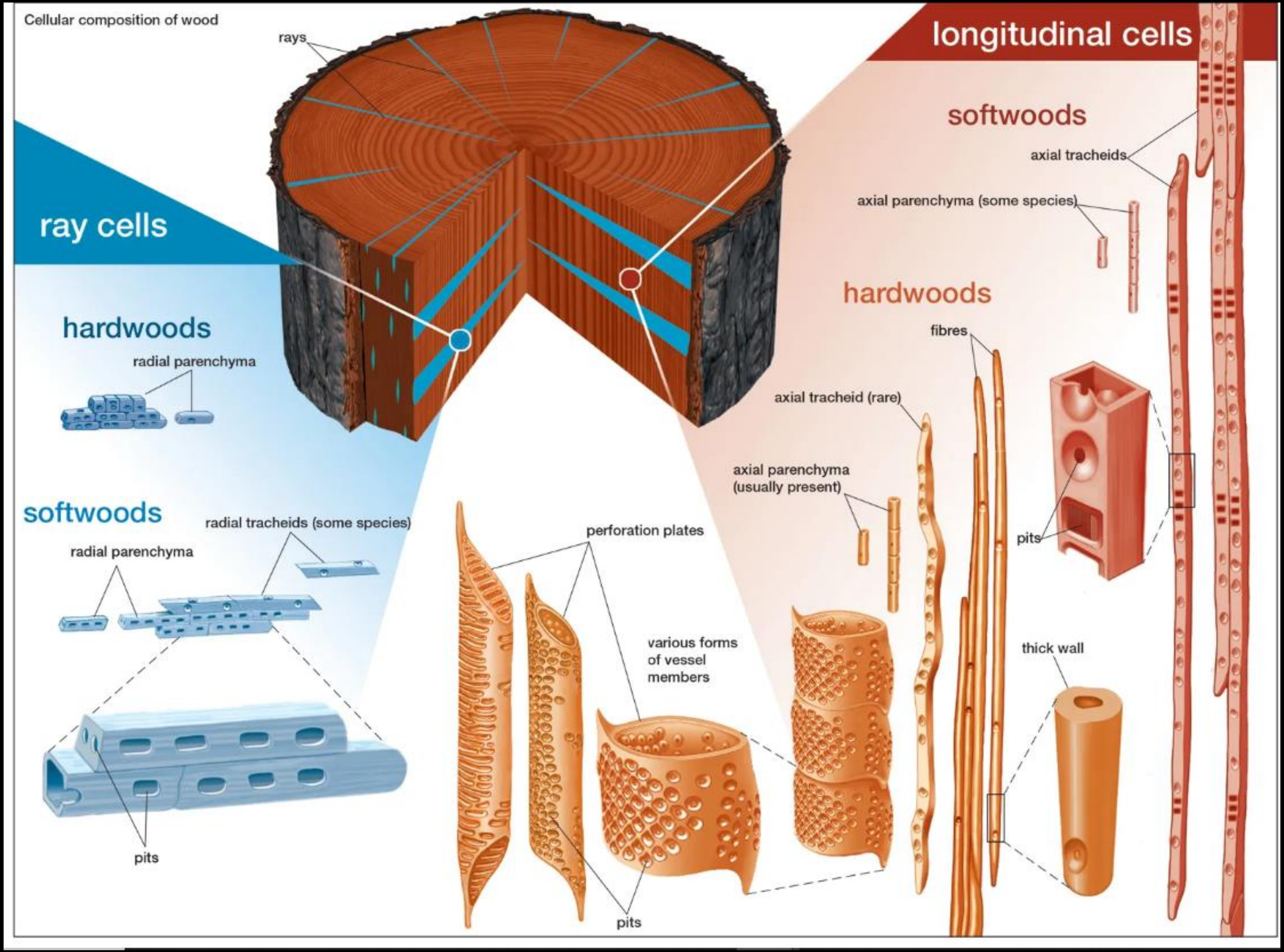
- remover agua de la madera en una razón de tiempo aceptable manteniendo la mejor calidad posible.
  - Entender el enfoque en los factores mas deseados; la razón de tiempo del secado o la calidad obtenible
  - Se puede comprometer la calidad si se buscar secar la madera de una manera mas ligera
  - Estos factores contribuyen para decidir que método de secado se deberá utilizar

Por que secar la madera

- Aumentar la demanda y las posibles ganancias
- Mejorar las propiedades físicas y mecánicas de la madera
- La madera seca es mas estable
- La madera seca es mas fácil de trabajar

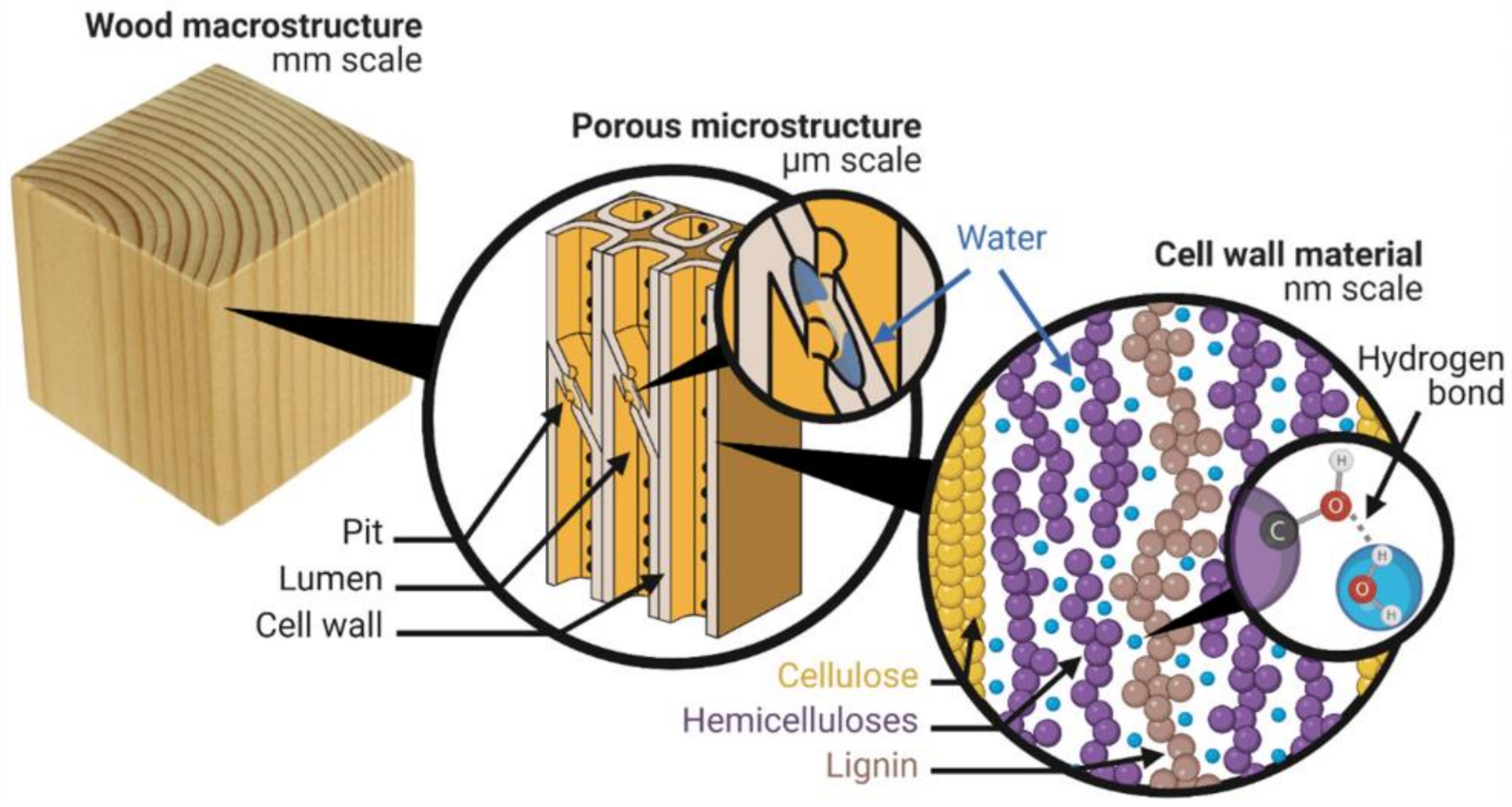


Fuente: researchoutreach.org



Fuente: britanica.com

Figure 1. Water in different locations in wood. Cell wall water is found inside the solid cell walls where it interacts with the hydroxyls of the constituent polymers (cellulose, hemicelluloses, lignin) by hydrogen bonds. Capillary water is found in the porous microstructure of wood, e.g., in pits and lumina.



Fuente: Thybring et al. 2022

Contenido de humedad

- El peso del agua en la madera relativo al peso de la madera seca, expresado en porcentaje

$$\%CH = \frac{\text{Peso mojado} - \text{Peso secado al horno}}{\text{Peso secado al horno}} \times 100$$

Equipos para medir contenido de humedad

Higrómetro

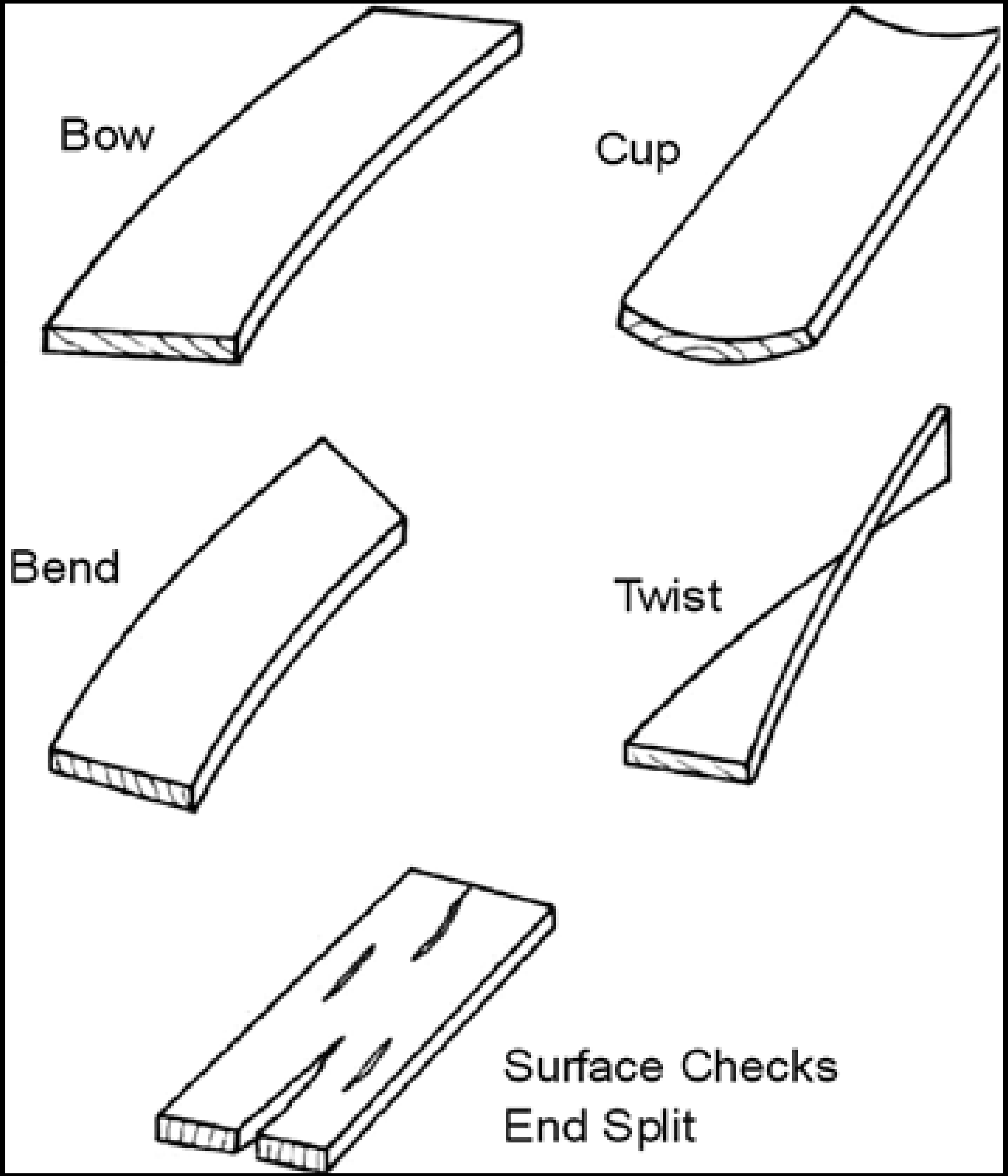
Secado de la madera

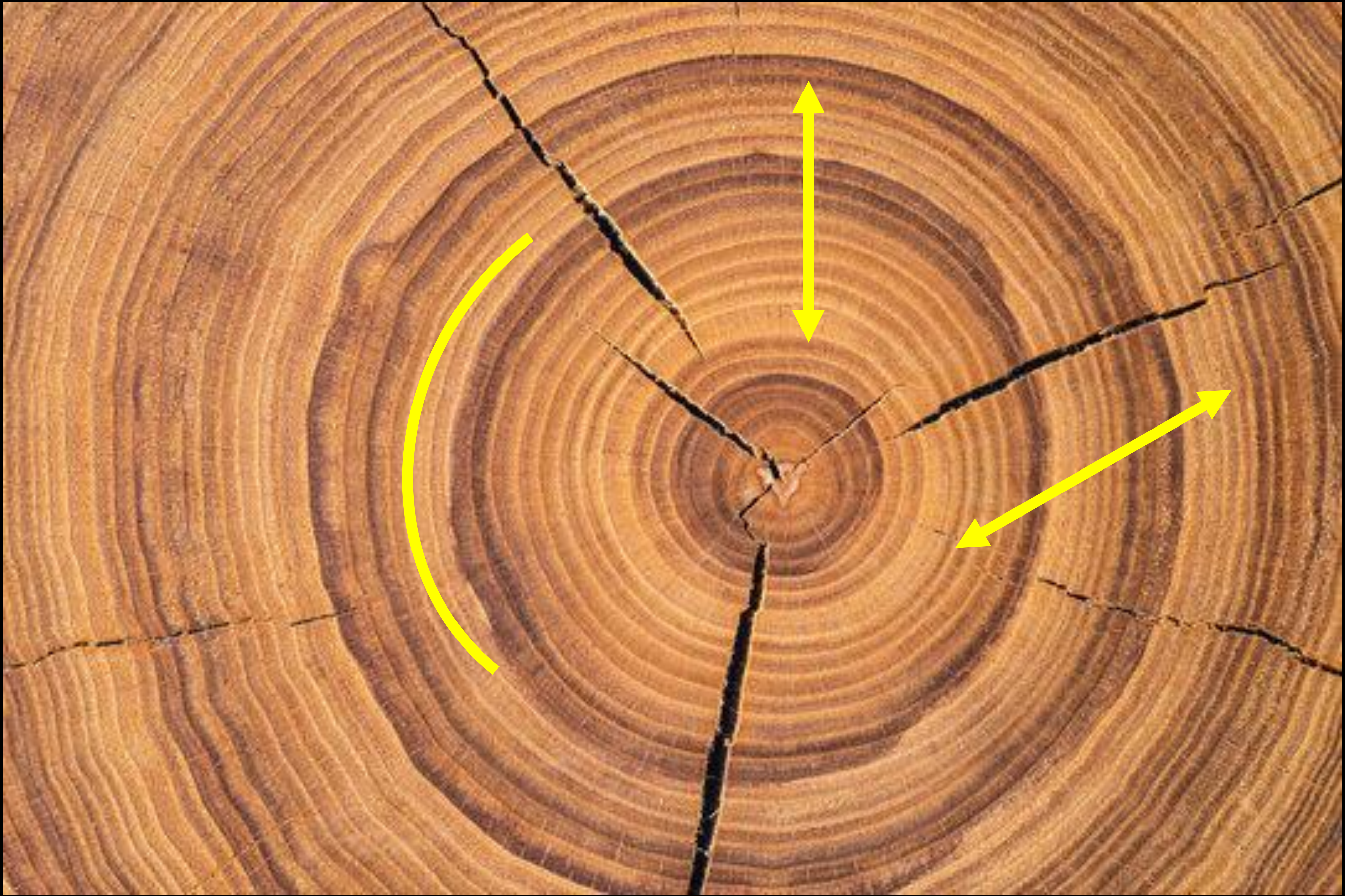
Secado de la madera

- Luego que un tronco es aserrado y la madera se apila con separadores, la madera comienza a perder humedad.
  - Agua libre
  - Agua ligada
- Cuando toda el agua libre se remueve, la madera alcanza el Punto de Saturación de la Fibra.
  - Generalmente ocurre cuando la madera alcanza un contenido de humedad de un 26%-30%
  - Solo queda el agua atada dentro de las paredes celulares

Defectos de secado

- Grietas y rajaduras
- Desviación de canto “cup”
- Desviación de llano “Bow”
- Desviación de filo “Bend”
- Torceduras “twist”





Contenido de humedad en equilibrio

- La madera es un material higroscópico
  - Capacidad para absorber o liberar humedad
- Fluctuaciones en contenido de humedad basados en las condiciones ambientales (temperatura y humedad relativa)
- La madera siempre va a buscar estar en un equilibrio donde no absorbe o libera humedad
  - A esto se le conoce como el contenido de humedad en equilibrio, o EMC por sus siglas en ingles

Table 1—Dependence of equilibrium moisture content (EMC) of wood on relative humidity (RH) and temperature

	EMC (%)																		
Temperature (°F (°C))	5% RH	10% RH	15% RH	20% RH	25% RH	30% RH	35% RH	40% RH	45% RH	50% RH	55% RH	60% RH	65% RH	70% RH	75% RH	80% RH	85% RH	90% RH	95% RH
30 (–1.1)	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.4	13.5	14.9	16.5	18.5	21.0	24.3
50 (10.0)	1.4	2.6	3.6	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.3	11.2	12.3	13.4	14.8	16.4	18.4	20.9	24.3
70 (21.1)	1.3	2.5	3.5	4.5	5.4	6.2	6.9	7.7	8.5	9.2	10.1	11.0	12.0	13.1	14.4	16.0	17.9	20.5	23.9
90 (32.2)	1.2	2.3	3.4	4.3	5.1	5.9	6.7	7.4	8.1	8.9	9.7	10.5	11.5	12.6	13.9	15.4	17.3	19.8	23.3
110 (43.3)	1.1	2.2	3.2	4.0	4.9	5.6	6.3	7.0	7.7	8.4	9.2	10.0	11.0	12.0	13.2	14.7	16.6	19.1	22.4
130 (54.4)	1.0	2.0	2.9	3.7	4.5	5.2	5.9	6.6	7.2	7.9	8.7	9.4	10.3	11.3	12.5	14.0	15.8	18.2	21.5
150 (65.6)	0.9	1.8	2.6	3.4	4.1	4.8	5.5	6.1	6.7	7.4	8.1	8.8	9.7	10.6	11.8	13.1	14.9	17.2	20.4

Fuente: Simpson 1998 (USFS)

EMC en San Juan, Puerto Rico

12.5% - 13.9%

Table 2—Equilibrium moisture content (EMC) of wood, exposed to outdoor atmosphere, in U.S. locations-con.

		EMC (%)											
State	City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug.	Sep	Oct	Nov	Dec
NM	Albuquerque	10.4	9.3	8.0	6.9	6.8	6.4	8.0	8.9	8.7	8.6	9.6	10.7
NM	Clayton	10.5	10.1	9.7	9.1	9.9	9.7	10.6	10.8	10.4	9.8	10.5	10.8
NM	Roswell	10.7	9.6	8.0	7.4	8.1	8.3	9.1	9.9	10.5	9.7	10.0	10.2
NV	Elko	13.3	12.5	11.1	10.0	9.5	8.7	7.3	7.4	8.0	9.1	11.8	13.2
NV	Ely	12.2	11.8	10.9	9.7	9.3	8.0	7.2	7.7	8.0	9.2	10.9	11.9
NV	Las Vegas	8.5	7.7	7.0	5.5	5.0	4.0	4.5	5.2	5.3	5.9	7.2	8.4
NV	Reno	12.3	10.7	9.7	8.8	8.8	8.2	7.7	7.9	8.4	9.4	10.9	12.3
NV	Winnemucca	12.9	11.7	10.4	9.1	8.7	7.7	6.1	6.3	7.2	8.7	11.3	13.2
NY	Albany	13.5	12.8	12.4	11.4	12.0	12.4	12.6	13.6	14.3	13.8	13.9	14.2
NY	Binghamton	15.0	14.3	13.7	12.5	12.6	13.2	13.2	14.3	15.1	14.4	15.0	15.7
NY	Buffalo	15.0	14.9	14.2	12.6	12.2	12.4	12.3	13.2	13.7	13.7	14.6	15.2
NY	Islip	13.2	12.7	12.8	12.5	12.4	12.4	13.3	13.6	13.9	13.7	13.4	12.8
NY	New York	12.2	11.9	11.5	11.0	11.5	11.8	11.8	12.4	12.6	12.3	12.5	12.3
NY	Rochester	14.3	14.3	13.7	12.5	12.3	12.6	12.6	13.6	14.4	14.2	14.6	15.4
NY	Syracuse	14.2	13.9	13.4	12.2	12.3	12.6	12.7	13.8	14.6	14.1	14.6	15.1
OH	Akron	14.6	13.9	13.2	12.2	12.4	12.8	13.0	14.0	14.1	13.5	14.0	14.8
OH	Cincinnati	14.5	13.8	13.1	12.2	12.6	12.9	13.2	13.9	13.9	13.2	13.9	14.8
	Cleveland	14.6	14.2	13.7	12.6	12.7	12.7	12.8	13.7	13.8	13.3	13.8	14.6
OH	Columbus	14.2	13.7	12.6	12.0	12.6	12.6	13.0	13.7	13.8	13.1	13.9	14.6
OH	Dayton	14.5	14.1	13.4	12.4	12.3	12.3	12.6	13.4	13.7	13.2	14.4	15.2
OH	Mansfield	15.4	14.9	13.8	12.6	12.8	13.0	13.2	14.1	14.1	13.4	14.6	16.0
OH	Toledo	14.9	14.3	13.8	12.8	12.4	12.7	13.3	14.3	14.4	13.8	14.7	15.8
OH	Youngstown	15.3	14.8	13.9	12.6	12.5	12.8	13.2	13.7	14.3	13.8	14.6	15.7
OK	Oklahoma City	13.2	12.9	12.2	12.1	13.4	13.1	11.7	11.8	12.9	12.3	12.8	13.2
OK	Tulsa	13.3	12.7	12.1	12.1	13.7	13.5	12.2	12.5	13.8	12.8	13.1	13.5
OR	Astoria	17.2	16.6	16.3	16.2	16.3	16.4	16.0	16.4	16.4	16.9	17.6	17.8
	Burns	12.8	12.6	10.1	8.1	7.7	7.3	5.9	6.1	6.7	8.6	11.9	14.5
OR	Eugene	18.9	17.4	15.7	14.6	14.0	13.1	11.6	11.7	12.3	15.6	18.9	20.2
OR	Medford	16.7	14.1	13.0	12.1	11.3	10.3	9.4	9.4	10.0	12.1	16.5	17.8
	Pendleton	15.8	14.0	11.6	10.6	9.9	9.1	7.4	7.7	8.8	11.0	14.6	16.5
OR	Portland	16.5	15.3	14.2	13.5	13.1	12.4	11.7	11.9	12.6	15.0	16.8	17.4
OR	Salem	16.9	15.8	14.4	13.9	13.4	12.8	11.6	11.6	12.3	14.6	17.8	18.0
PA	Allentown	13.3	12.8	12.1	11.7	12.0	12.2	12.4	13.3	13.8	13.6	13.5	13.7
PA	Avoca	13.7	13.2	12.5	11.7	11.9	12.9	13.0	13.6	14.4	13.7	13.9	14.1
PA	Erie	14.8	14.6	13.8	13.0	13.1	13.4	13.6	13.8	14.0	13.4	13.7	14.5
PA	Harrisburg	12.4	11.9	11.7	11.2	11.7	11.9	12.1	12.8	13.3	13.1	12.8	12.5
PA	Philadelphia	12.6	11.9	11.7	11.2	11.8	11.9	12.1	12.4	13.0	13.0	12.7	12.7
PA	Pittsburg	13.8	13.2	12.7	11.5	11.9	12.1	12.6	13.2	13.6	12.9	13.5	14.1
PA	Williamsport	13.3	12.8	12.5	11.6	12.2	12.9	13.3	14.0	14.7	14.0	13.9	13.7
PC	Guam	16.3	16.2	15.8	15.6	16.3	16.4	17.9	18.6	18.9	18.4	17.5	16.5
PC	Koror	15.2	14.9	14.6	14.4	15.1	15.5	15.5	15.5	15.0	15.2	15.0	15.2
PC	Marshall Islands	15.0	14.6	15.0	15.9	16.0	16.0	15.9	15.7	15.5	15.5	15.7	15.5
PC	Pago Pago	16.4	16.4	16.6	16.8	16.6	15.9	15.6	15.4	15.2	15.7	15.7	15.7
PC	East Caroline Is.	15.3	15.0	15.2	15.8	16.4	16.6	17.0	16.8	16.6	16.8	16.6	16.0
PC	Wake Island	13.3	13.3	13.8	14.0	14.1	14.1	14.2	14.7	14.7	14.5	14.1	13.5
PC	West Caroline Is.	14.7	14.3	13.9	13.8	14.4	15.0	15.2	15.5	15.4	15.4	15.2	15.0
PR	San Juan	13.7	13.2	12.6	12.5	13.2	13.3	13.5	13.4	13.5	13.6	13.9	13.8
RI	Providence	12.0	11.7	11.7	11.1	11.8	12.1	12.2	12.6	13.0	12.7	12.8	12.5
SC	Charleston	13.3	12.6	12.5	12.4	12.8	13.5	14.1	14.6	14.5	13.7	13.2	13.2
SC	Columbia	13.0	12.3	12.3	11.8	12.4	12.7	13.2	14.0	14.0	13.5	13.4	13.1
SC	Greenville	12.6	11.9	11.9	11.6	12.7	13.0	13.4	14.1	14.2	13.6	12.7	12.7

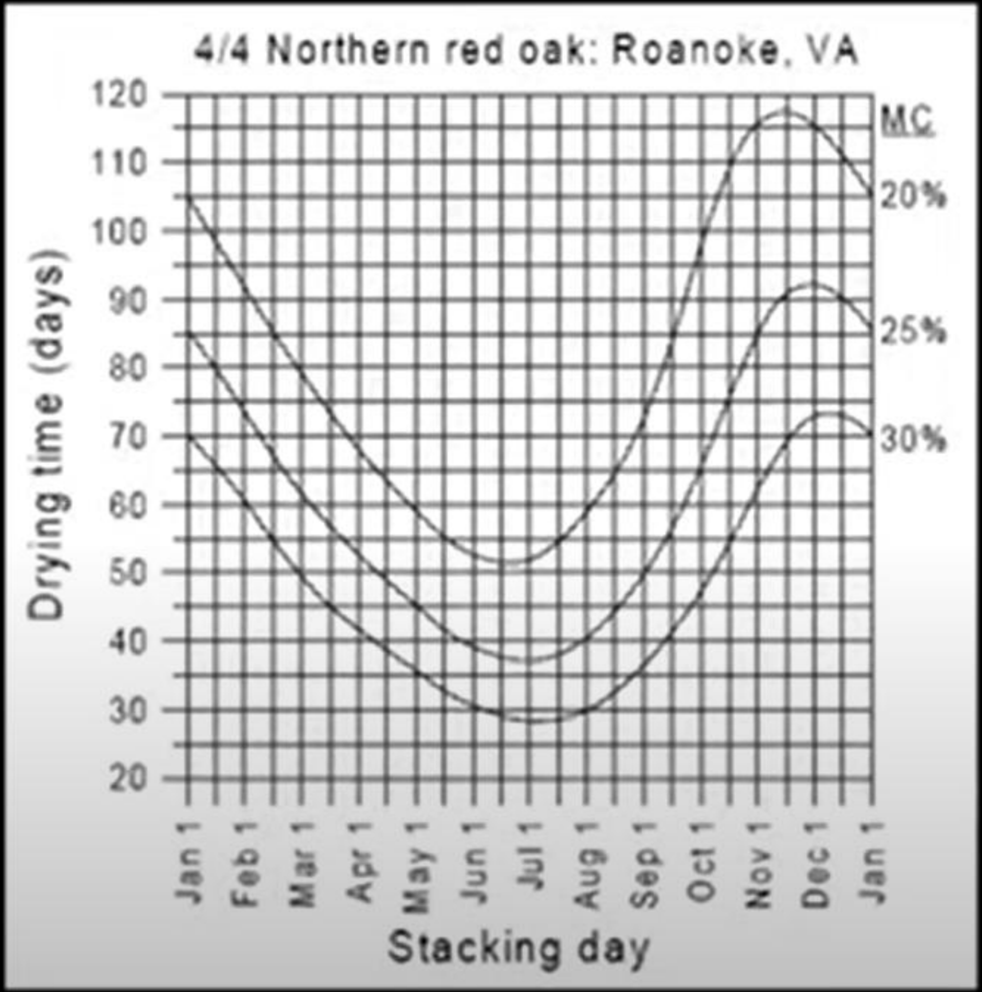
Fuente: Simpson 1998 (USFS)

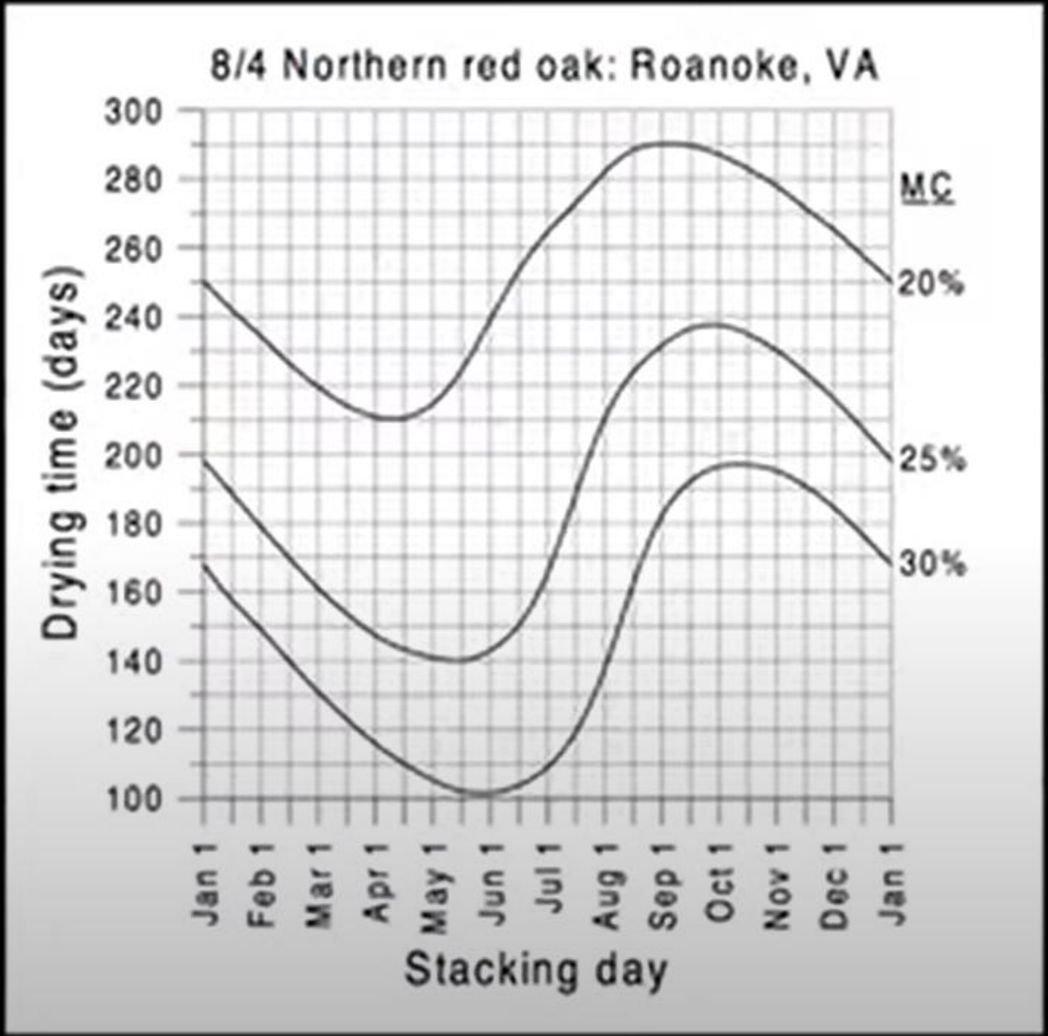
Secado al aire

- Menos costosos y mas sencillo
- Mas común en PR
- Tiende a tardar mas
- Limita el porcentaje de humedad al cual puedes llegar
- Comúnmente utilizado con otros métodos de secado

Fuente: UNH Extension

Secado al aire





Fuente: Bond 2021

Horno de deshumificación

- Utiliza un deshumificador para bajar la humedad relativa en la cámara de secado
- Secado mas parejo
- Hay que seguir régimen/horario de secado
- Consume mas electricidad

Fuente: woodmizer.com

Horno de calor directo o indirecto

- Utiliza Fuente de calor para calentar el aire dentro de la recamara y secar la madera
- Mas utilizados por empresas de alta producción
- Mayor cantidad de defectos en la madera si nos se utiliza correctamente
- Alcanza altas temperaturas
- Se puede utilizar la quema de desperdicios para energía

Fuente: kiln-direct.com

Horno de vacío

- Los mas costosos
- Horno mas rápido para secar madera
- Crea un vacío y disminuye la presión atmosférica, lo cual disminuye la temperatura de evaporación del agua
- La mejor opción para secar maderas difíciles de secar como los “slabs”
- La presión ayuda a minimizar los defectos del secado

Fuente: vacutherm.com

Fuente: idrywood.com

Secador solar

- Utiliza la energía solar para calentar el espacio dentro de la recamara de secado
- Puede utilizarse sin electricidad
- Su eficiencia depende grandemente de factores climatológicos
- Mas rápido que el secado al aire pero mas lento que otras alternativas
- No es muy útil para madera gruesa y ancha

Secador solar

FOREST PRODUCTS LABORATORY (Madison 5, Wis.)
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
Approved Technical Article

Drying by Solar Radiation in Puerto Rico

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In Puerto Rico, and in the tropics in general, there are very few dry kilns. Often lumber is processed at a moisture content higher than 30 percent, resulting in problems during manufacturing, finishing, and in use. Research on solar drying at the U. S. Forest Products Laboratory led to the construction of the first solar dryer in the tropics in Puerto Rico, and the results have been promising. The use of solar heat may, because of its low cost, provide a readily acceptable solution to the lumber drying problems of this region.

THE WOODWORKING INDUSTRIES OF Puerto Rico are dependent upon imported lumber, most of which is not air dry when it reaches the island. None of the local furniture or millwork plants possess adequate facilities for drying lumber, either an air-drying yard or a dry kiln. Even storage space is inadequate, so the common practice is to store lumber in solid piles out-of-doors with no protection from damp local climate. Lumber from such piles usually enters the production line with no attention to moisture content. This practice occasionally causes difficulties when manufactured items are placed in service.

The local lack of concern with dryness of lumber has resulted in only minor problems until recently. The low shrinkage coefficients and the grain characteristics of mahogany (*Swietenia macrophylla* King), the most commonly used wood, prevent many of the defects which might otherwise be anticipated. Furthermore, the local climate, with no requirement of interior heat, maintains a relatively uniform, h i g h, equilibrium moisture content. However, this same climatic characteristic is unfavorable to air drying and makes unattainable by this technique a moisture content sufficiently low for marketing locally manufactured products under the drier use conditions prevailing in most of the continental United States.

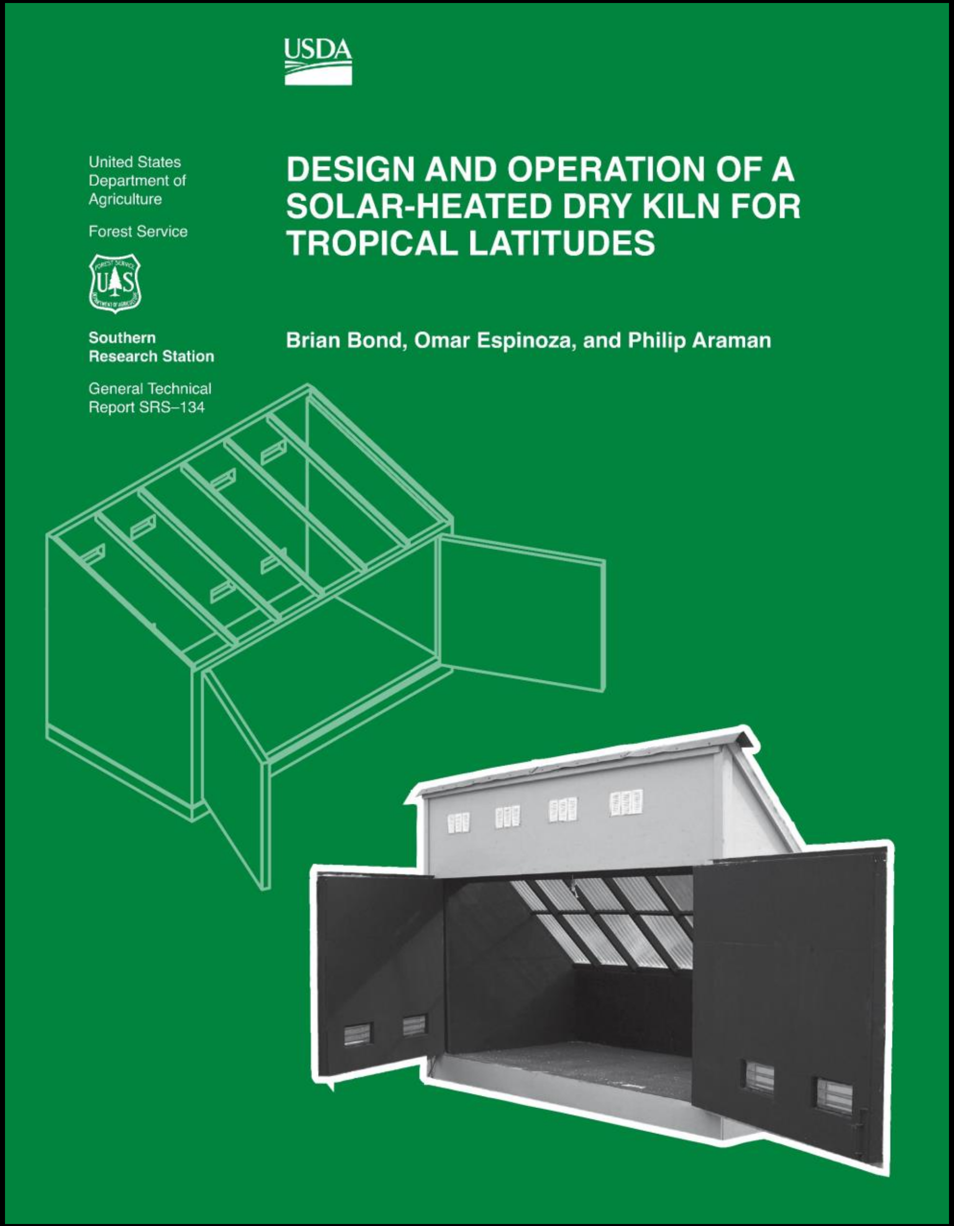
Recent experiments at the Forest Products Laboratory at Madison, Wisconsin, suggested that solar energy might be an effective and inexpensive basis for drying lumber in Puerto Rico. At Madison, a solar dryer had been designed and tested with results that indicated the possibility of commercial use of this method in areas receiving high solar radiation. As a consequence, the Institute of Tropical Forestry set up a cooperative research program with the E. I. DuPont de Nemours and Company, and the Forest Products Laboratory. DuPont was interested in obtaining exposure data on a new type of transparent plastic film used in the construction of the drier.

The Solar Dryer

A pilot dryer with a capacity of 2,000 board feet was constructed at a cost of approximately $2,000 at a location subject to day-long sunlight on the grounds of the Institute at Rio Piedras, Puerto Rico (see the figure). The structure is 10 feet wide (north to south) by 14 feet, 8 inches long (east to west). The south wall is 9 feet 9 inches high and the north wall is 13 feet 4 inches, making the southward pitch angle of the roof about 16°, or approximately perpendicular to the mean position of the sun at noon in this latitude. The structure rests on a reinforced concrete slab, to which it is anchored by bolts through sill plates. The framework is 2- by 4-inch dimension stock. The north wall is sheathed with plywood. The roof and all other walls are sheathed, both outside and inside, with transparent plastic films, providing an insulating dead-air thickness of about 1½ inches. The west wall contains a pair of hinged doors of the same construction. Small louvered vents were set in the lower corners of the east and west walls.

Within the dryer is mounted a heat-absorbing surface consisting of a corrugated metal sheet, painted black, and set parallel to but about 12 inches beneath the roof. Near the peak of the roof are mounted four 16-inch fans perpendicular to but centered in line with this heat absorbing surface, and powered by a 1½ horsepower motor mounted outside the north wall. Baffles around the fans and beneath the heat-absorbing surface to the top of the lumber pile located centrally within the dryer force circulation of the internal air past the heat absorbing surface, downward, on the south side, through the lumber pile, and back upward on the north side into the fans. A slight pressure differential

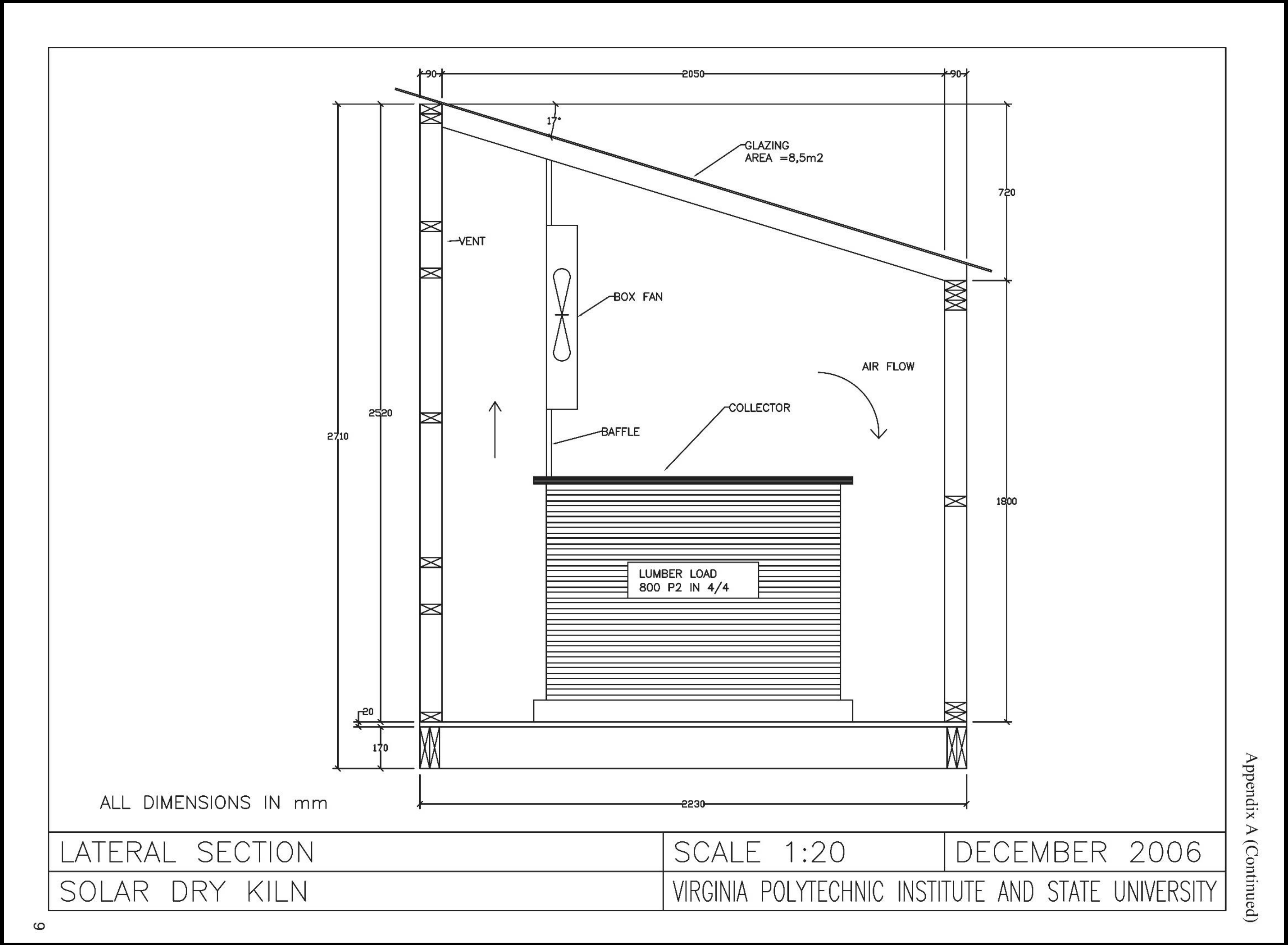
[1]Presented at the 16th Annual Meeting of the Forest Products Research Society, Session 14 (Division 8, Wood Drying), Spokane, Wash., June 20, 1962.



Asunciones generales

- 1 pie cuadrado de colector puede producir alrededor de 1,000 BTU's por día en promedio
- Para evaporar 1 libra de agua de la madera se requiere alrededor de 1,000 BTU's
- Peso del agua en la madera = Volumen de madera en pies cúbicos x Gravedad especifica de la madera x 62.4 x (CH verde – CH deseado en decimal)
- Diseño del horno solar permite secar madera a una razón de 10 pies tablares por cada pie cuadrado de colector para obtener una Perdida de 2% de CH por día

Construcción del horno solar



Velocity Field Comparison

- Improved flow distribution between lumber boards from initial design iteration.

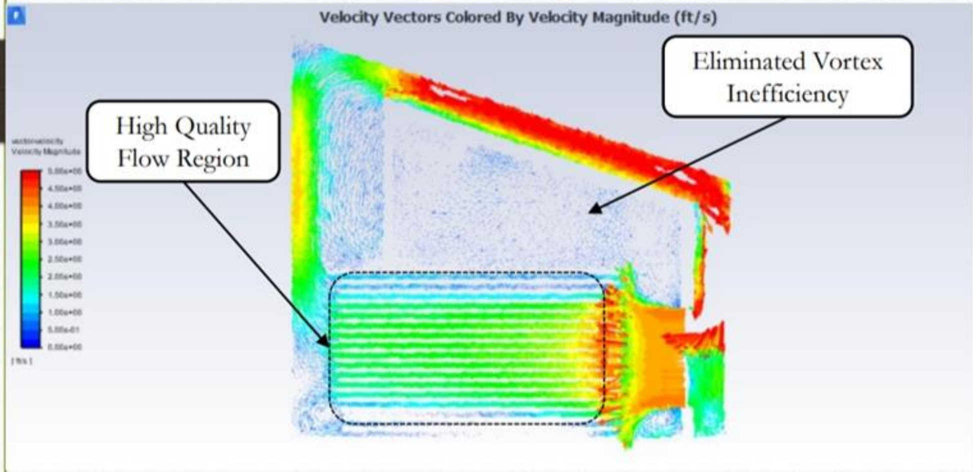


Figure 9: Final kiln design center plane velocity vector field.

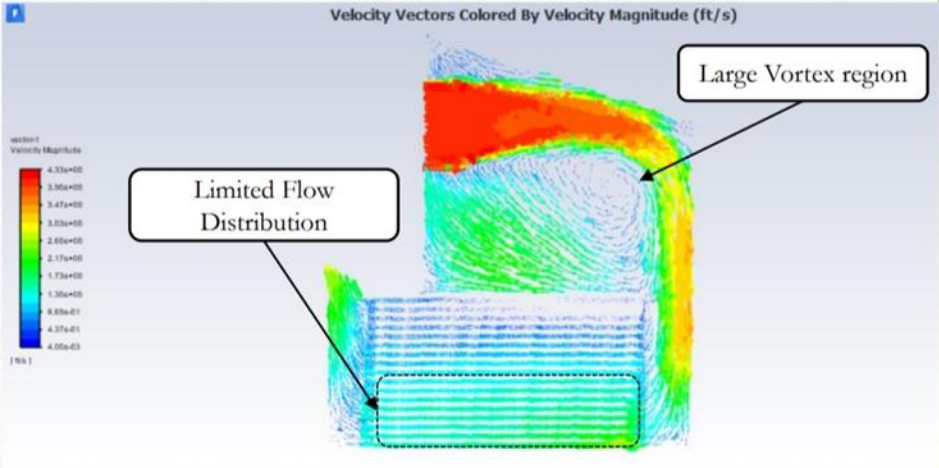


Figure 10: Initial kiln design center plane velocity vector field.


PINK
NEXT GEN
FIBERGLAS
R13


PINK
NEXT GEN
FIBERGLAS
R13


PINK
NEXT GEN
FIBERGLAS
R13
OWENS CORNING


PINK
NEXT GEN
FIBERGLAS
R13

Monitoreo durante operación

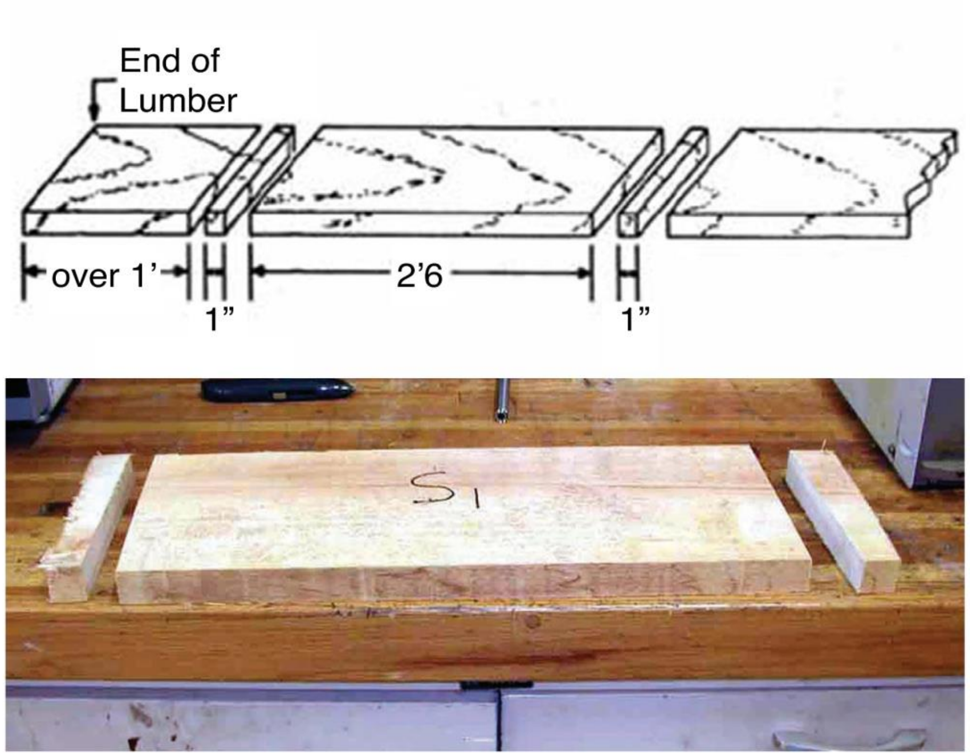


Figure 7—Dimensions and picture of sample board for controlling the drying process.

Figure 9—Pack of lumber with sample boards.

$$\text{Estimated oven dry weight (g)} = \frac{\text{Weight of wet sample board}}{100+\text{MC\%}} \qquad [2]$$

$$\text{Current MC(\%)} = \left(\frac{\text{Current weight of sample board}}{\text{Estimated oven dry weight}} - 1\right) \text{X } 100\% \qquad [3]$$

¿Preguntas ?