DRYING LUMBER WITH A SOLAR KILN

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SUSTAINABLE BIOMATERIALS

Why do we dry wood?

- To gain value added

4/4 Thickness	Green ($/MBF)	Dry ($/MBF)
Red Oak FAS	965	1395
Red Oak 1 Com	685	1020
Hard Maple FAS	1375	1585
Hard Maple 1 Com	1060	1140
Yellow-poplar FAS	840	1105
Yellow-poplar 1 Com	455	695

September 21, 2018 Appalachian

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Why do we dry wood?

- To gain entrance to market
  - Who uses green wood?

Wood Moisture Effects

- Strength
- Treating
- Durability
- Machining
- Gluing
- Assembly
- Finishing
- Use
- Weight
- Dimensional stability

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What is the goal of the drying process?

- Usually:
  - To drive water out of wood at an acceptable rate of speed with the maximum obtainable quality
    - Reach a target moisture content with minimal degrade and cost

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Moisture Content

The weight of water in wood relative to the dry weight of the wood, expressed as a percentage

$$\%MC = \frac{\text{Wet Weight - Oven Dry Weight}}{\text{Oven Dry Weight}} X100$$

$$\%MC = \left(\frac{\text{Wet Weight}}{\text{Oven Dry Weight}} - 1 \right) X100$$

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Moisture Content (oven dry basis)

$$\%MC = \frac{0.90\,\text{kg} - 0.60\,\text{kg}}{0.60\,\text{kg}} X100 = 50\%MC$$

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Moisture Contents

- Green - fresh sawn lumber
- Air-dry- dried to ambient conditions
- Kiln-dry- should be specified 6-12%
  - Lumber for Indoor Conditions
- Oven-dry- all water removed 0%mc

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How do we dry wood?

- The two most common methods of drying lumber are:
  - Air drying
  - Air drying and then kiln drying
  - Kiln drying

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How do we dry wood?

- What are the limitations?:
  - Air drying
  - Air drying and then kiln drying
  - Kiln drying

How much control over conditions?

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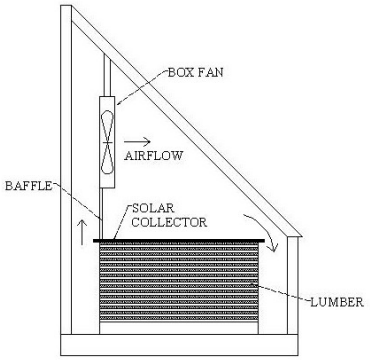
What do we need to dry wood?

- How does a kiln work?
- A kiln controls three factors
  - Temperature
  - Humidity
  - Air flow



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Relative Humidity

$$\frac{\text{Amount of moisture in air}}{\text{Total possible amount of moisture at that temperature}} \times 100 = \%\text{Relative Humidity}$$

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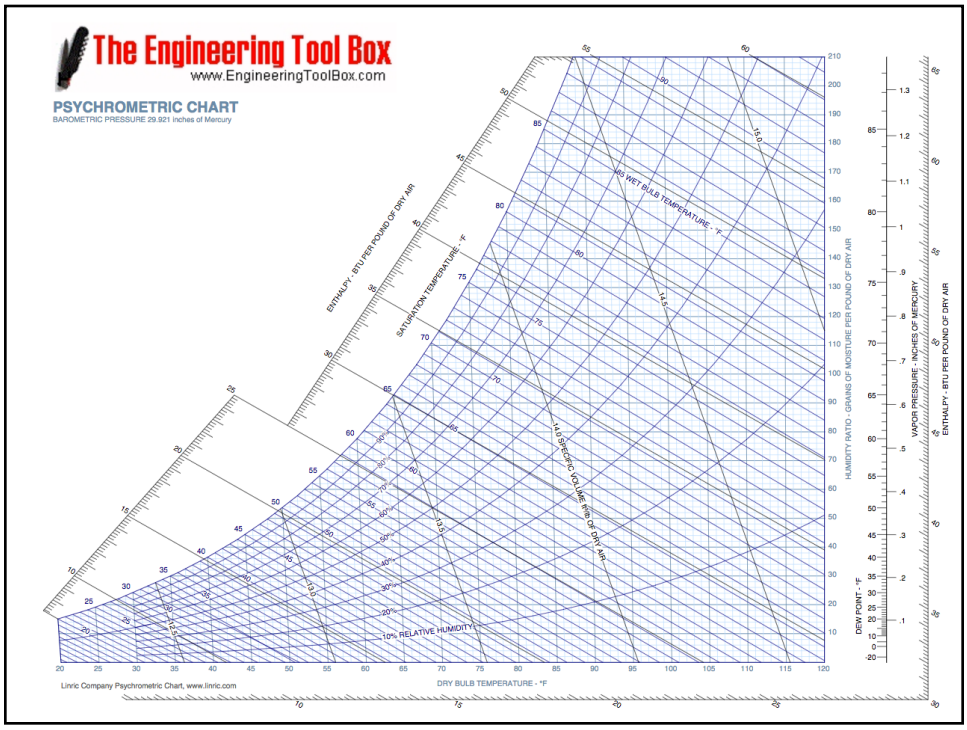
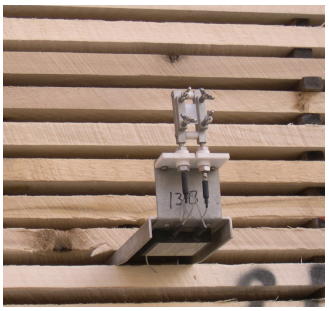


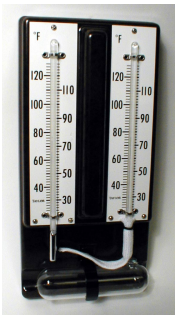
Temperature, RH, and EMC

Table 3–4. Moisture content of wood in equilibrium with stated temperature and relative humidity

Temperature		Moisture content (%) at various relative humidity values																		
(°C	(°F))	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%
–1.1	(30)	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
4.4	(40)	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.3	13.5	14.9	16.5	18.5	21.0	24.3
10.0	(50)	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
15.6	(60)	1.3	2.5	3.6	4.6	5.4	6.2	7.0	7.8	8.6	9.4	10.2	11.1	12.1	13.3	14.6	16.2	18.2	20.7	24.1
21.1	(70)	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
26.7	(80)	1.3	2.4	3.5	4.4	5.3	6.1	6.8	7.6	8.3	9.1	9.9	10.8	11.7	12.9	14.2	15.7	17.7	20.2	23.6
32.2	(90)	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
37.8	(100)	1.2	2.3	3.3	4.2	5.0	5.8	6.5	7.2	7.9	8.7	9.5	10.3	11.2	12.3	13.6	15.1	17.0	19.5	22.9
43.3	(110)	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
48.9	(120)	1.1	2.1	3.0	3.9	4.7	5.4	6.1	6.8	7.5	8.2	8.9	9.7	10.6	11.7	12.9	14.4	16.2	18.6	22.0
54.4	(130)	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
60.0	(140)	0.9	1.9	2.8	3.6	4.3	5.0	5.7	6.3	7.0	7.7	8.4	9.1	10.0	11.0	12.1	13.6	15.3	17.7	21.0
65.6	(150)	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
71.1	(160)	0.8	1.6	2.4	3.2	3.9	4.6	5.2	5.8	6.4	7.1	7.8	8.5	9.3	10.3	11.4	12.7	14.4	16.7	19.9
76.7	(170)	0.7	1.5	2.3	3.0	3.7	4.3	4.9	5.6	6.2	6.8	7.4	8.2	9.0	9.9	11.0	12.3	14.0	16.2	19.3
82.2	(180)	0.7	1.4	2.1	2.8	3.5	4.1	4.7	5.3	5.9	6.5	7.1	7.8	8.6	9.5	10.5	11.8	13.5	15.7	18.7
87.8	(190)	0.6	1.3	1.9	2.6	3.2	3.8	4.4	5.0	5.5	6.1	6.8	7.5	8.2	9.1	10.1	11.4	13.0	15.1	18.1
93.3	(200)	0.5	1.1	1.7	2.4	3.0	3.5	4.1	4.6	5.2	5.8	6.4	7.1	7.8	8.7	9.7	10.9	12.5	14.6	17.5
98.9	(210)	0.5	1.0	1.6	2.1	2.7	3.2	3.8	4.3	4.9	5.4	6.0	6.7	7.4	8.3	9.2	10.4	12.0	14.0	16.9
104.4	(220)	0.4	0.9	1.4	1.9	2.4	2.9	3.4	3.9	4.5	5.0	5.6	6.3	7.0	7.8	8.8	9.9			
110.0	(230)	0.3	0.8	1.2	1.6	2.1	2.6	3.1	3.6	4.2	4.7	5.3	6.0	6.7						
115.6	(240)	0.3	0.6	0.9	1.3	1.7	2.1	2.6	3.1	3.5	4.1	4.6								
121.1	(250)	0.2	0.4	0.7	1.0	1.3	1.7	2.1	2.5	2.9										
126.7	(260)	0.2	0.3	0.5	0.7	0.9	1.1	1.4												
132.2	(270)	0.1	0.1	0.2	0.3	0.4	0.4													

Ways to Measure Humidity





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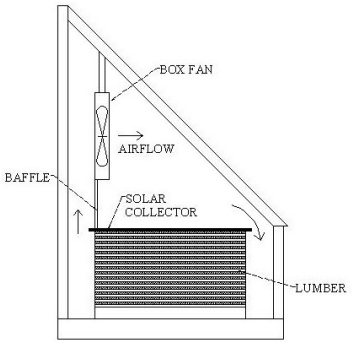
How does a solar kiln work?

Heat / Temperature

- What influences the temperature in the kiln?
- Does it change during the drying process?



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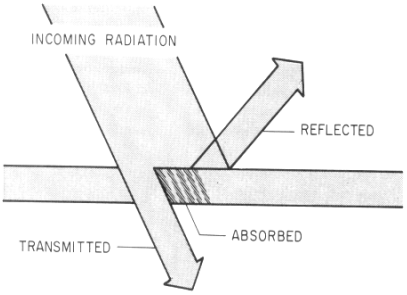
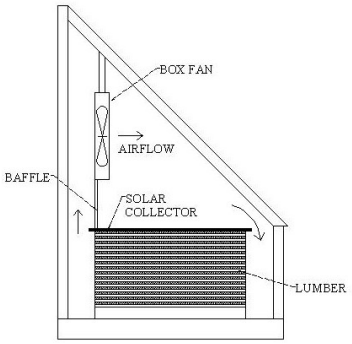
Collector Design –The Glazing

- Long or infrared waves trapped or reflected back





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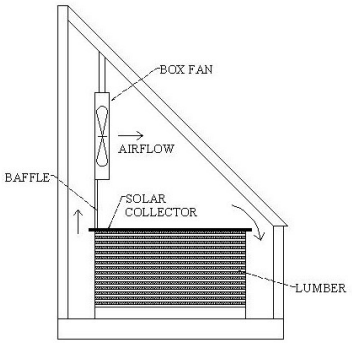
How does a solar kiln work?

Humidity

- What influences the relative humidity in the kiln?
- Does it change during the drying process?



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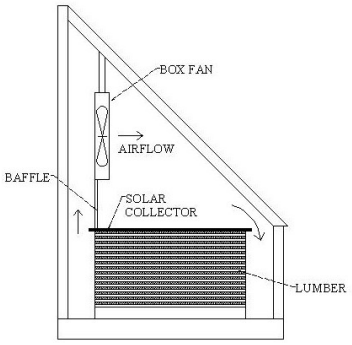
How does a solar kiln work?

Airflow

- What influences the airflow in the kiln?
- Does it change during the drying process?



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VT Solar Kiln: Basic Design

- Semi-Greenhouse
  - Usually only roof clear but maybe south wall
  - Glazing any type
  - Good thermal insulation
  - Better control of drying

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Where to start?

- Lets start with looking at the solar collector and the amount of heat needed to dry lumber

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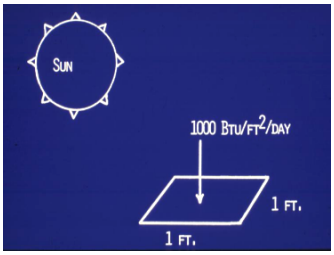
General Assumptions



- 1 square foot of collector can produce about 1000 BTU's per day (based on a 12 month average)
- It takes about 1000 BTU's to evaporate about one pound of water from wood (a reasonable design average)

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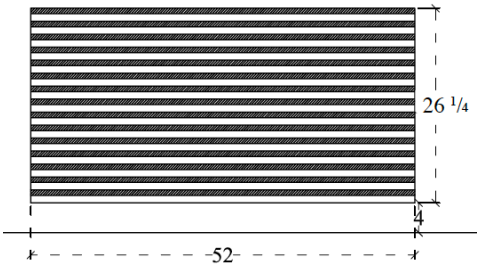
General Assumptions: How much water to remove?

Lumber in kiln is:

- 52” wide/12” = 4.33 ft
- 1.125/12 x 15 layers = 1.41 ft
- 12’ length

12 x 4.33 x 1.41= 73.26 cubic feet of wood



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How Much Water in Wood A Quick Estimate . . .

Weight of water = Volume of wood in cubic feet x Specific gravity of wood x 62.4 x (Green MC – Final MC in decimal)

73.26 x 0.56 x 62.4 x (.77 – .07) =

1792 pounds of water to remove from 800 bd.ft. of red oak from 77 to 7 % MC

SUSTAINABLE BIOMATERIALS

How Much Water in Wood
A Quick Estimate . . .

- How many btu's per day to loose 2% MC in red oak?

  Weight of water = Volume of wood in cubic feet x Specific gravity of wood x 62.4 x (Green MC – Final MC in decimal)

- 73.26 x 0.56 x 62.4 x (.77 – .75) =
  - 65.5 pounds of water for a 2% MC loss in 4/4 red oak
  - 65.5 x 1,000 btu/lb.– 65,500 btu

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The Collector Size?

- Collector:
  - 96 x 144 –inches
  - 8 ft x 12 ft = 96 sq feet
- 96 cu ft x 1000 btu/cu ft/day = 96,000/day @ 100% efficiency
  - Assume 50% efficiency……..
    - 96,000 / 0.50 = 48,000 btu…..
  - Assume 60% efficiency……..
    - 96,000 / 0.6 = 57,600 btu…..

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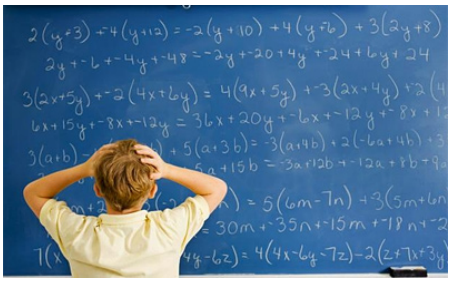
Confused?



- Our design is based on drying 4/4 red oak, so if you maintain approximately 10bd ft to 1 sq ft of collector, you will be just fine!
- We designed to kiln so that if it is properly loaded (10 bd ft : 1 sq ft collector) the kiln will not check lumber

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VT Solar Kiln Design

- Based on 25 years of research and development on the solar drying of lumber in USA and foreign countries

- Designed with two major objectives:
  1) be relatively inexpensive to construct
  2) be simple to operate
     - Collector size limits temperature

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Bulding

- How'd we build it?

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Construction

Pressure Treated wood for base

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Construction

Plastic to prevent condensation

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Construction

- Standard framing techniques
- Door location

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Construction

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Construction

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Glazing

- **Tuftex 144-in Clear Corrugated Polycarbonate Roof Panel**
  - Square wave profile
  - Temperatures 270°F to -40°F
  - 100% UV protected
  - The clear panel lets 90 percent of light shine through

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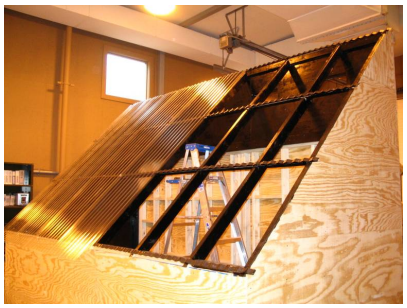
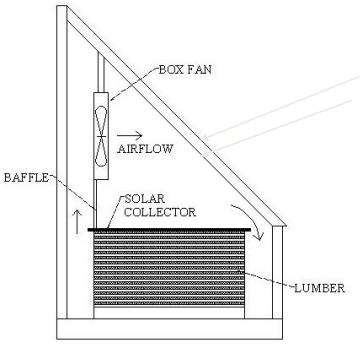
Glazing

- One or two layers?
  - Insulation





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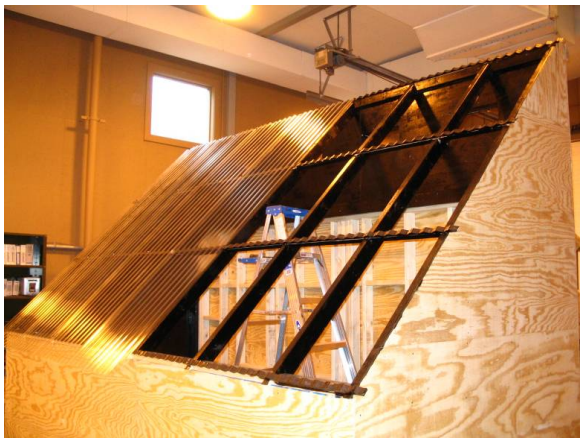
Collector Design –

- Glazing



Construction

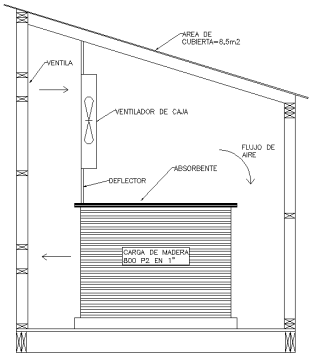
– Rear Vents

– Loading and Sample Door

Construction

Fans

- Three inexpensive plastic fans
  - Watch heat when unloaded!



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Fans

- About 100 to 150 fpm through the load
- Length x No. layers x Sticker thickness x Air-Velocity
- 12 ft x 20 layers x 3/48 sticker thickness x 100 fpm air-velocity equals 1500 cpm

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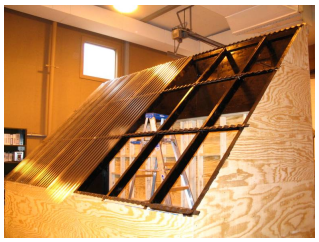
Construction

- Paint Interior
  - Humidity barrier
  - Black: Solar collector
- Exterior paint
  - For durability



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Roof Cap

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Condensation?

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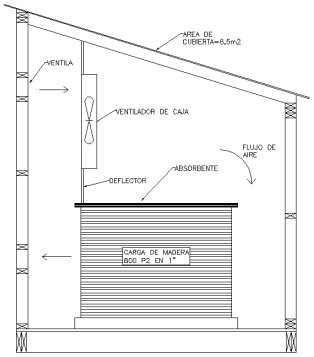
Air-flow: Baffle and Plenum



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Air-flow and Humidity Control

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Completely Solar?

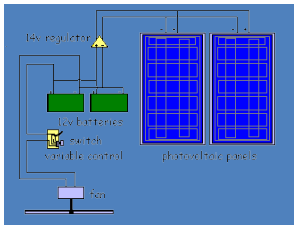
•Can the kiln be designed to be completely solar?

– Option 1

– Solar panel to charge batteries to run fans

– Option 2

• Solar panel to run fans



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Self-Contained Solar

- Option 1. AC fan using solar power to operate fan.
  - Source:
  - Creative Energy Technologies Inc
    2872 State Rt 10
    Summit, NY 12175 USA
    www.cetsolar.com/

Parts required		Cost
16" ac fan		$ 20.00
20 Watt Solar panel	Part #SPS20	$202.00
Mounting kit for solar panel		$ 79.00
Battery 250 watt hour deep cycle	Part # UB-8D	$360.00
Charge controller for battery	Part #SS-6L	$ 65.58
400 Watt DC to AC power Inverter	Part # Veco24	$ 49.90
		Total $776.57/per fan

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Option 2 – Home center attic fan

- 500 cfm each fan
- 179 each fan
- $537 for three

Solar Kiln Info
www.Solarkilninfo.com

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Adaptations

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Transportable Kiln

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Original VT Kiln

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Dianne Griffin

Solar Kiln Class 2014

SUSTAINABLE BIOMATERIALS

Solar Kiln Class 2010

Section I

SUSTAINABLE BIOMATERIALS

Colorado

Section I

SUSTAINABLE BIOMATERIALS

Robin Jones (Solar Kiln Class 2002)

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Where to Start?

- The kiln is built and you have some wood sawn…….you are ready(?)

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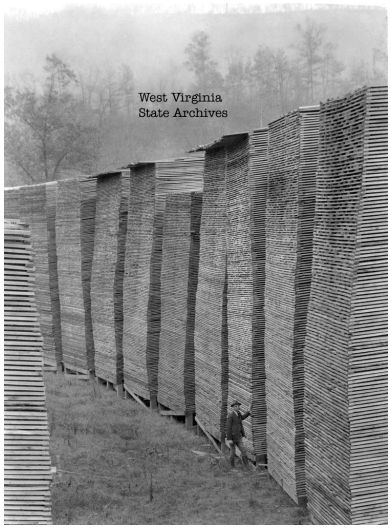
Stacking Lumber



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Where do you start?

- Get the lumber on sticks

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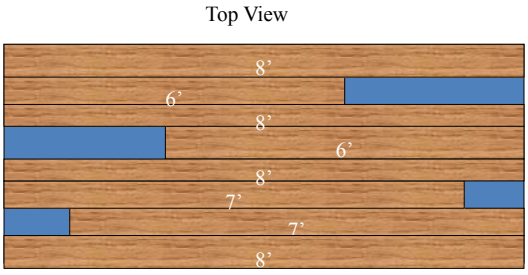
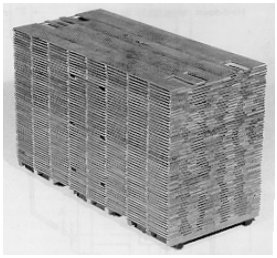
Stacking

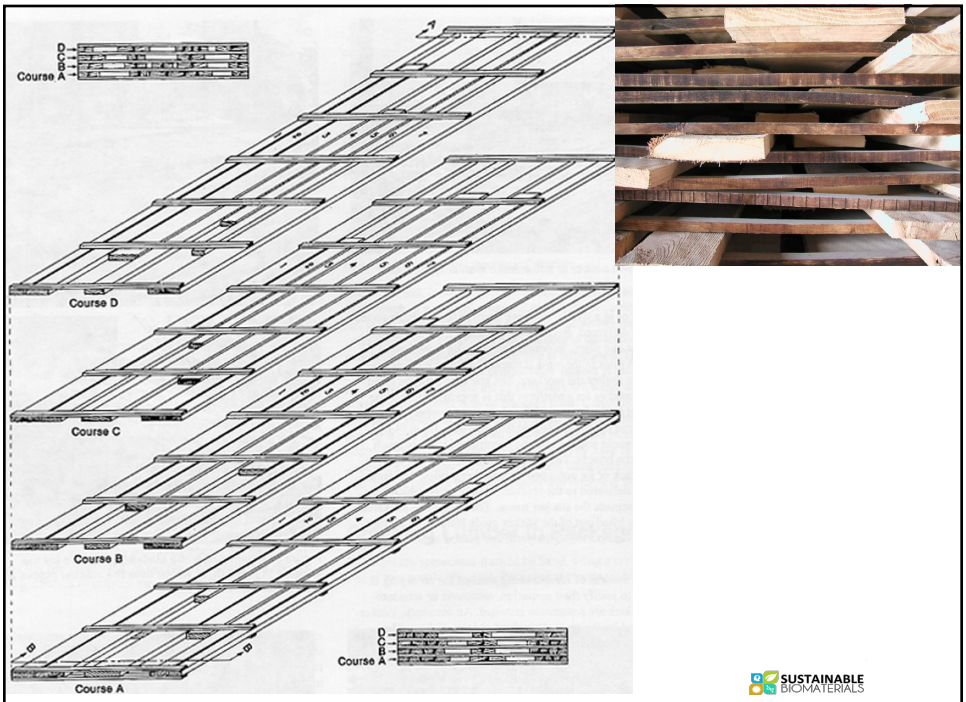
- Get the lumber on sticks
  - Promote uniform air circulation
    - heat
    - humidity
  - Reduce or eliminate warp

Stacking Practices

- Box-piling







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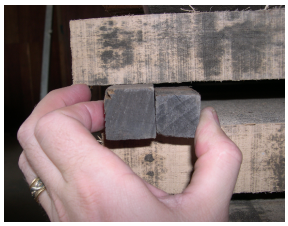
Stickers

- **Thickness**
  - ¾" to 7/8"
  - speed and uniformity
  - Typical
    - **Thinner stickers increase kiln capacity**
    - **Increase air velocity**
    - **Make air-flow more uniform**
- **Width**
  - 1-1/4" to 1 1/2 inch
  - Too wide – stain
  - Too narrow – improper placement
  - Strength is a function of width and thickness



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Stickers

- Spacing
  - 16” to 24”
    - Based on tendency to warp
  - Flush or as close as possible to the ends
    - Reduces warp and minimizes splitting
    - 12” on end for multiple length packs

SUSTAINABLE BIOMATERIALS

Stickers

- Quality
  - Straight grained
  - Hardwoods
  - Density
- Moisture Content
  - 9-12% MC
  - Keep them dry
    - (out of the rain)

Dry Green or Air-dry First?

- What is best?
- Why?

SUSTAINABLE BIOMATERIALS

Air-drying Lumber

- Level Pile Foundation
- Uniform weight distribution
- Pile cover

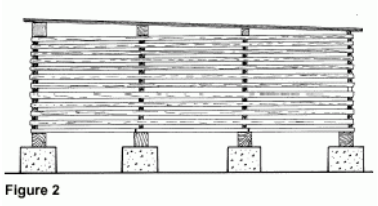

Figure 2

SUSTAINABLE BIOMATERIALS

Air Drying Factors




TAINABLE
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Best – Dry in an Open Shed




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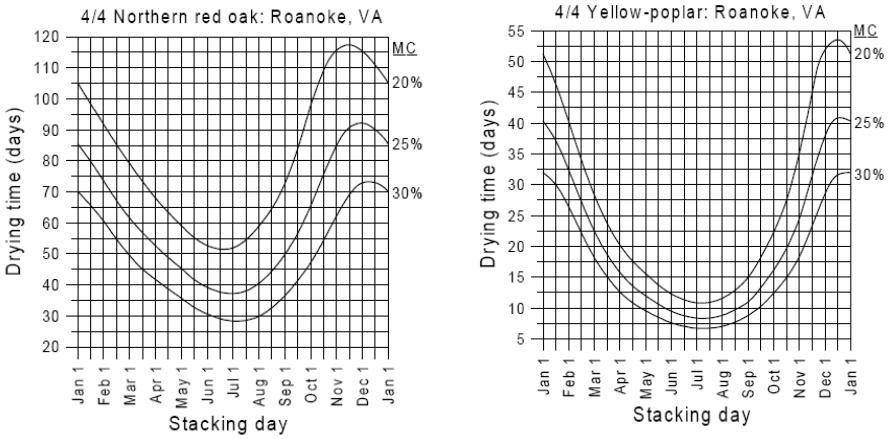
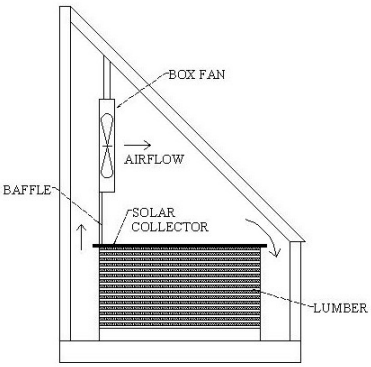
Air Drying Times

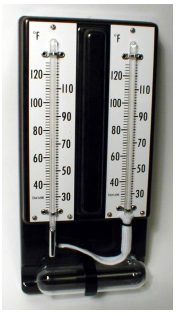




SUSTAINABLE BIOMATERIALS

Monitoring the Drying Process

- How much control do we need?
  - What can we really control?
- How much information is necessary?



SUSTAINABLE BIOMATERIALS

What is a kiln sample?

- A section 30” or more in length
- It is cut from a selected board
- Must dry at the same rate as the lumber
  - End coating
- Placed in the kiln charge so that it can be removed for examination, weighing and testing.

SUSTAINABLE BIOMATERIALS

Moisture Sections

$$Estimated\ Oven\ Dry\ Sample\ Wt = \frac{Original\ wt\ of\ sample.}{100+MC\ of\ smaple\ in\ \%}\ x\ 100$$

$$Est.\ Oven\ Dry\ Wt. = \frac{5.64\ lbs.}{100+69\ \%\ MC}\ x\ 100 = 3.334\ \text{lbs}$$

SUSTAINABLE BIOMATERIALS

Solar Kiln Controls

SUSTAINABLE BIOMATERIALS

Relative Humidity

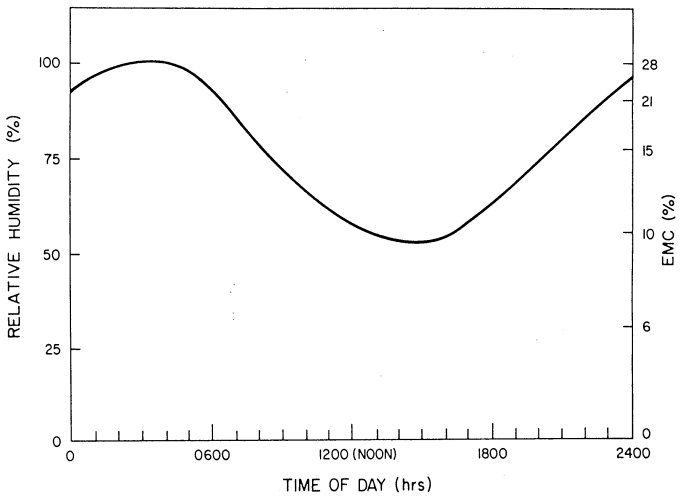


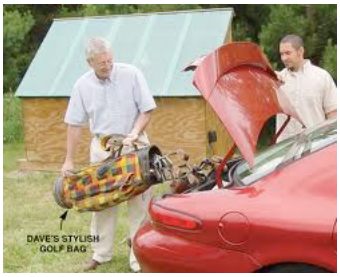
Figure 4

ABLE RIALS

SUSTAINABLE BIOMATERIALS

Example of Kiln Operation: I

- Sunrise:
  - Timer and thermostat turn on fans
- After Sunset:
  - Close vents and shut off fans



SUSTAINABLE BIOMATERIALS

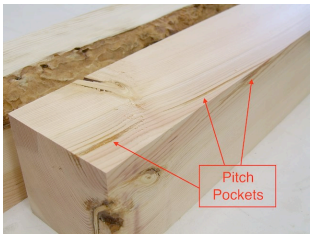
Example of Kiln Operation II

- Sunrise:
  - Timer and thermostat turn on fans
- Early morning:
  - Measure MC, max-min temperatures, and humidity
- Decide on conditions
- Late Morning / Early Afternoon:
  - Kiln heating up
- Mid Afternoon:
  - Check temperature and humidity
- After Sunset:
  - Close vents and shut off fans

SUSTAINABLE BIOMATERIALS

Setting the Pitch and Instects

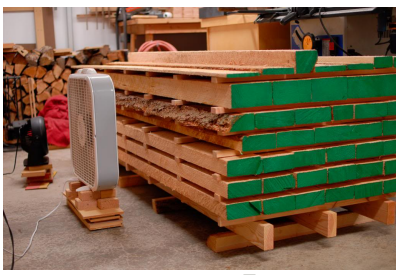
- Setting the Pitch
  - 180 F – 12 hrs
- Insects
  - Center of wood 132°F for 30 min.



SUSTAINABLE BIOMATERIALS

Thick Stock and Different Species

- Thick stock requires a slower drying rate
  - Reduce the collector size
- Easier to dry species can benefit from larger collector size
  - Less wood
  - Build with larger collector
- The Solar kiln has limits!
  - Use a different technology……..



SUSTAINABLE BIOMATERIALS

Direct-fired/Indirect-fired

- Examples:
  - Wood stove in building
  - Gas furnace heating
- Considerations:
  - Evenly heat building
  - Humidity control
  - Stress relief
  - Green or air-dried material
  - Can reach higher temperatures for sterilization and pitch setting

Kiln Direct

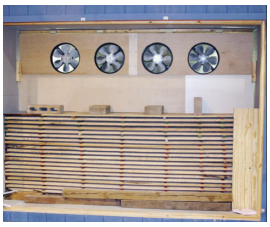
SUSTAINABLE BIOMATERIALS

Dehumidification kilns

- Removes water from air rather than venting
- Greater energy efficiency over steam/hot water conventional kilns
- Small to large sizes

American Woodworker #94 June 2002

Small D.H. Kiln Plans



- 600 Board foot kiln
- Year round operation
- Common building materials
- Common basement dehumidifier
- Electric heater
- Attic fans
- Total cost of materials $2,704 (2006)

University of Wisconsin Cooperative Extension
PUB FR-396 2007
http://www.dnr.state.wi.us/forestry/publications/pdf/FR-396-2007.pdf

SUSTAINABLE BIOMATERIALS

SUSTAINABLE BIOMATERIALS