USDA Forest Service
U.S. DEPARTMENT OF AGRICULTURE

Introduction to Lumber Dry Kiln Operations – Week 3

November 15, 2021

Hosted Virtually by the Southwest Ecological Restoration Institutes Wood Utilization Team

Instructor: Patrick Rappold, Regional Wood Utilization Specialist, USDA Forest Service Wood Education & Resource Center

Week 2 Agenda November 8, 2021

12:00pm MST – 1:00pm MST

- Introduction to relative humidity, dry bulb, wet bulb, and equilibrium moisture content. Followed by calculation exercises.
- The different stages of kiln drying.
- Introduction to lumber drying schedules.

1:00pm MST – 2:00pm MST

- Exercises on developing lumber dry kiln schedules.
- Phytosanitation guidelines and standards.
- Validating phytosanitation procedures.

Instructor

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Wood Innovations Funding Programs

October 19, 2021	Request for proposals announced
January 19, 2022	Proposal submission deadline
May 2022	Approximate date to announce awardees
August 2022	Approximate date of award

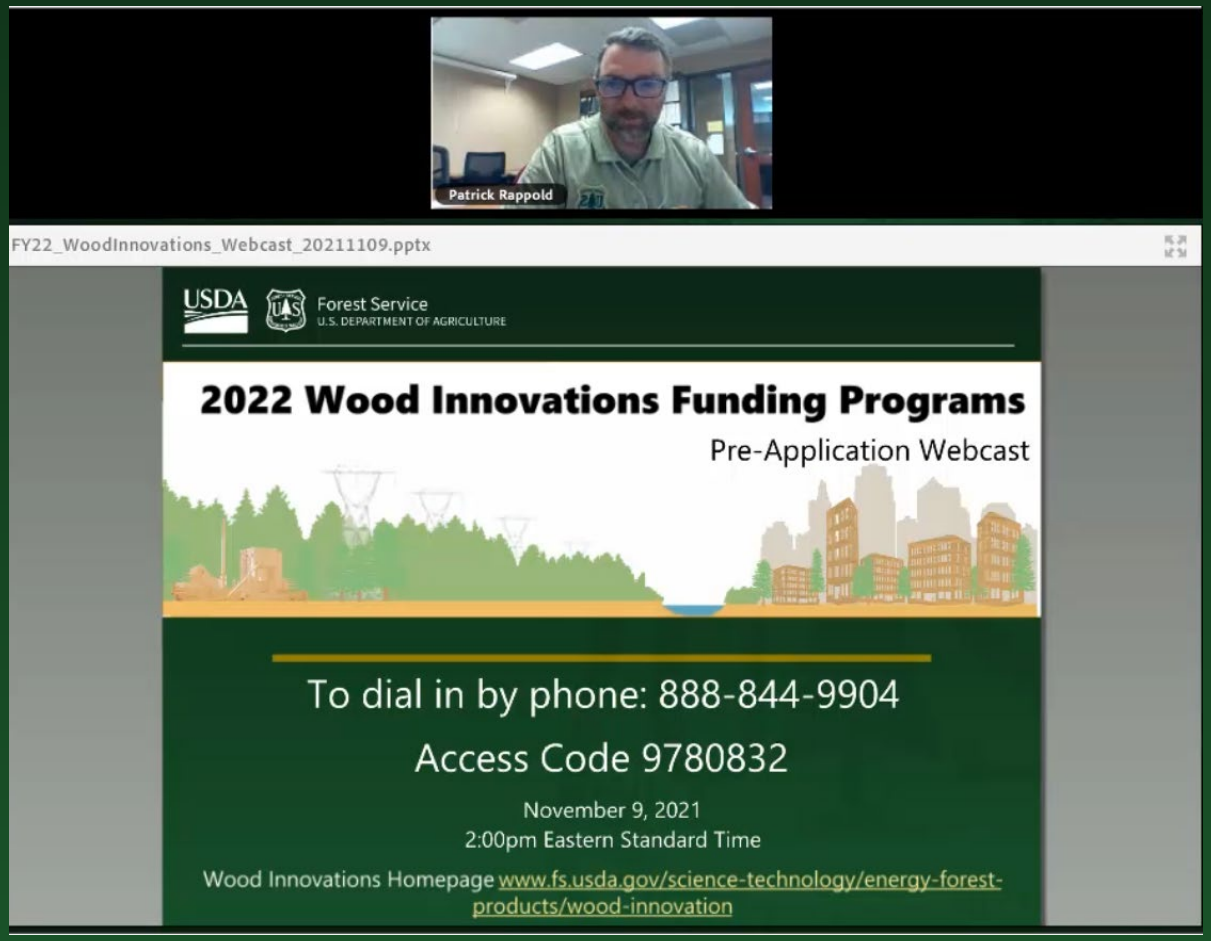
Wood Innovations Funding Opportunity; Catalog of Federal Domestic Assistance 10.674

Community Wood Funding Program; Catalog of Federal Domestic Assistance 10.708

Wood Innovations Webpage https://www.fs.usda.gov/science-technology/energy-forest-products/wood-innovation

FY22 Wood Innovations Webcast Recording; **November 9, 2021**

https://usfs.adobeconnect.com/pvs7p70t1cp4/



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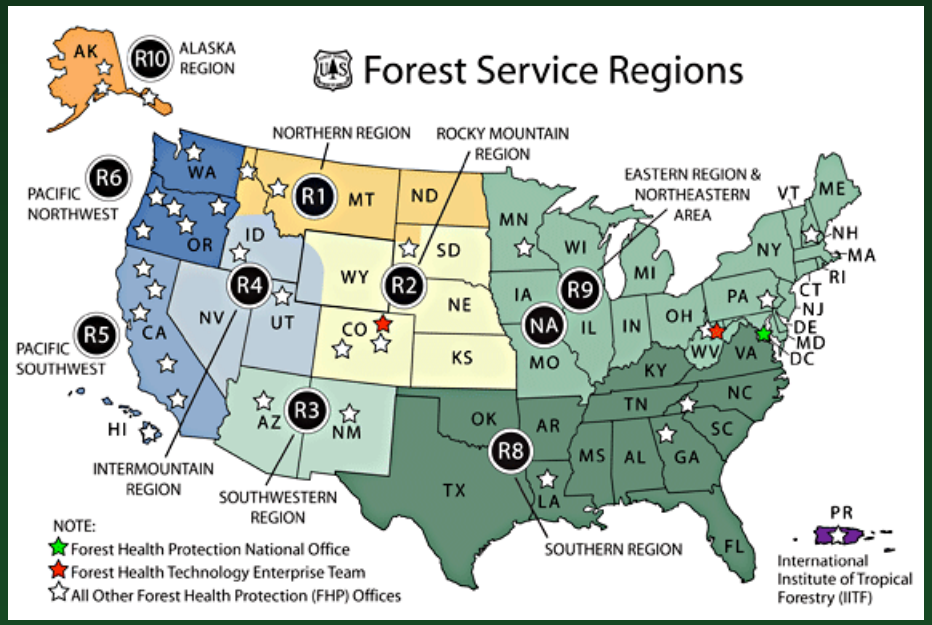

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Discussion of Pricing and Costs

Refrain from discussing lumber costs and purchasing activities.

Books and Materials

Dry Kiln Schedules for Commercial Woods, USDA Forest Service Forest Products Laboratory
https://www.fpl.fs.fed.us/documnts/fplgtr/fplgtr57.pdf

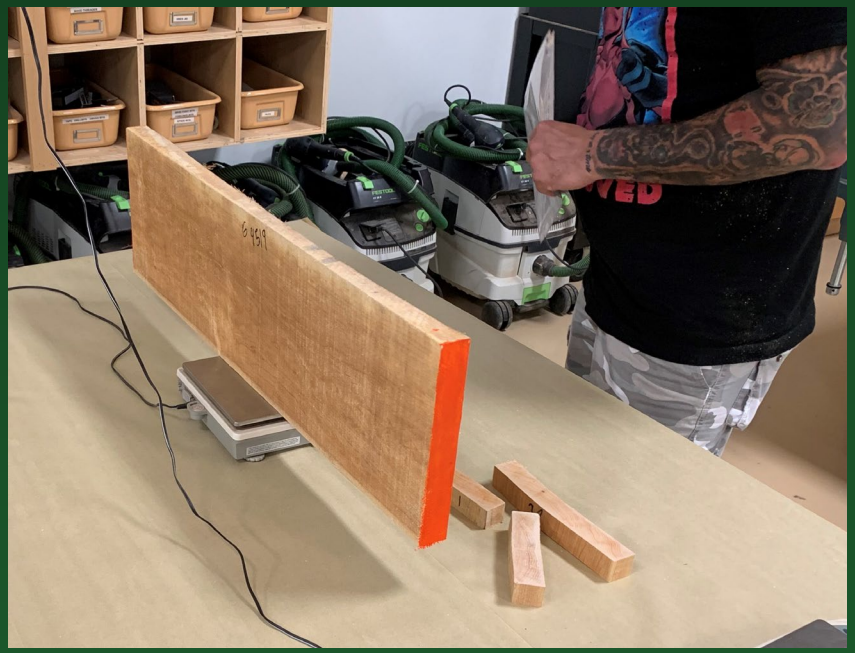
Dry Kiln Operator's Manual, USDA Forest Service Forest Products Laboratory – 1991 Edition
https://www.fs.usda.gov/treesearch/pubs/7164

Wood handbook- Wood as an engineering material – 2021 Edition, USDA Forest Service Forest Products Laboratory
https://www.fs.usda.gov/treesearch/pubs/62200

Week 2 Highlights

✓ Dry basis moisture content formula

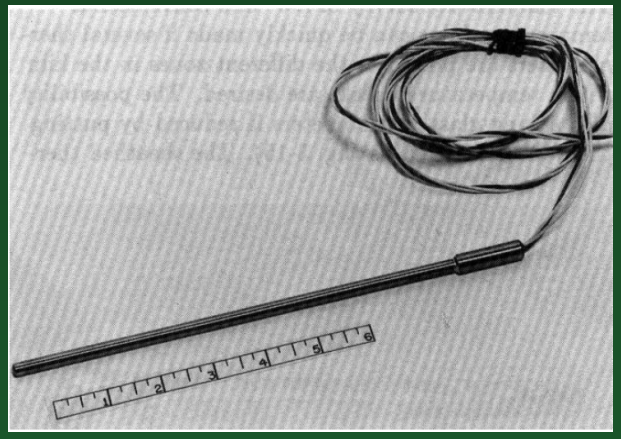
$$MC\ (\%) = \left[\frac{Original\ Weight\ (Green)}{Ovendry\ Weight\ (Dry)} - 1\right] 100$$



Week 2 Highlights

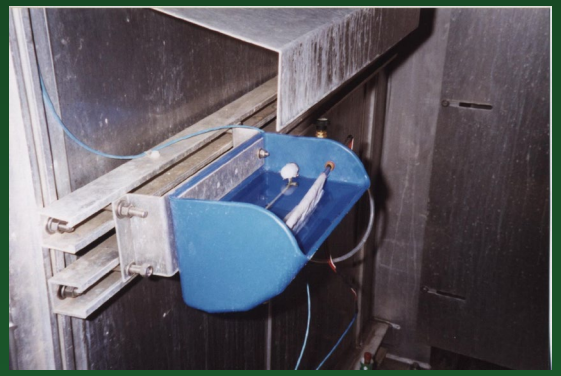
DRY BULB

- Resistance temperature detector (RTD)
- Measures air temperature



WET BULB

- Resistance temperature detector (RTD) with a damp cotton cloth.
- Relays information used to calculate relative humidity



Hygrometer – Calibrate Dry Bulb and Wet Bulb

- Routinely calibrate dry bulb and wet bulb detector readings with a hygrometer.
- Leave hygrometer in dry kiln for 30-minutes so it can acclimate to environment.
- Raise or lower dry bulb and wet bulb sensor readings as needed.
- Use clean wet bulb wicks that are free of mold.

Image Source: Conway-Cleveland Corporation
https://www.conwaycleveland.com/kiln-supplies-ovens/hygrometer-60-120f

Data Collectors

- Where does the dry bulb and wet bulb information go to?
- Data can be stored on hard drives
- Knowledge of Windows filing system is needed
- Hard drive data can be used for phytosanitation verification purposes

Equilibrium Moisture Content (EMC)

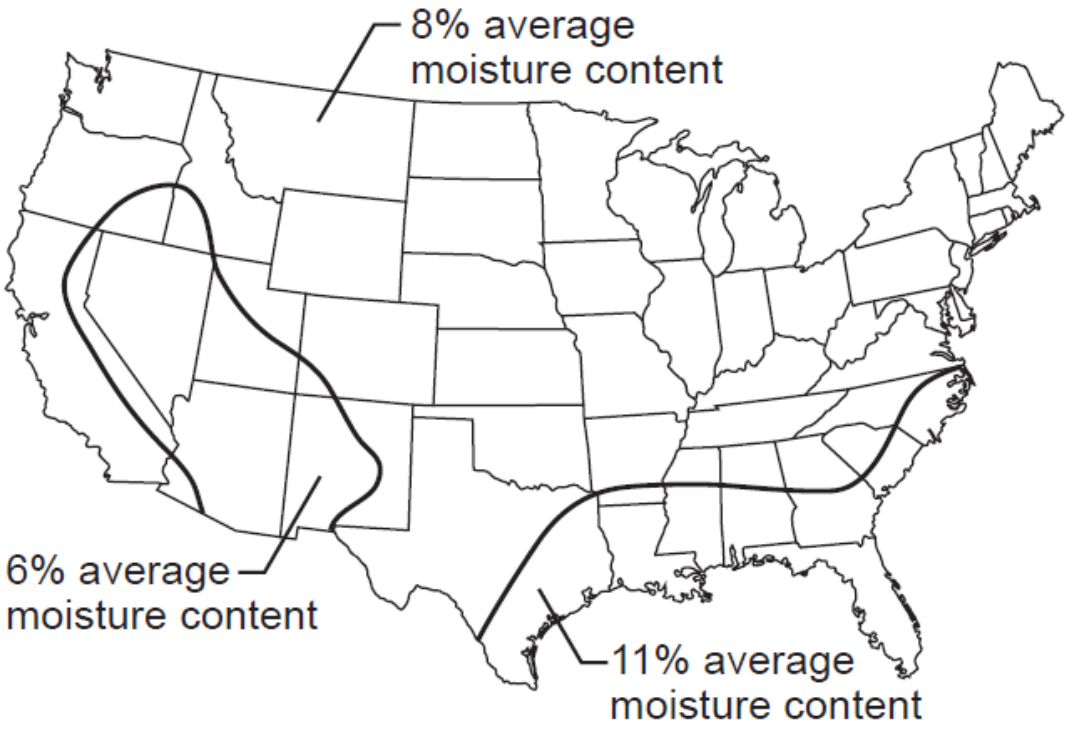


Figure 13–1. Recommended average moisture content for interior use of wood products in various areas of the United States.

Source: Wood Engineering Handbook, 2021

Equilibrium Moisture Content. The moisture content at which wood neither gains nor loses moisture when surrounded by air at a given relative humidity and temperature. - Wood Handbook: Wood as an Engineering Material, 2021

Table 13–2. Recommended moisture content values for various wood products at time of installation

	Recommended moisture content (%) for areas in the United States					
	Most areas of the United States		Dry southwestern area[a]		Damp, warm coastal area[a]	
Use of wood	Average[b]	Individual pieces	Average[b]	Individual pieces	Average[b]	Individual pieces
Interior: woodwork, flooring, furniture, wood trim	8	6–10	6	4–9	11	8–13
Exterior: siding, wood trim, sheathing, laminated timbers	12	9–14	9	7–12	12	9–14

[a]Major areas are indicated in Figure 13–1.
[b]To obtain a realistic average, test at least 10% of each item. If the quantity of a given item is small, make several tests. For example, in an ordinary dwelling containing 60 floor joists, at least six tests should be made on joists selected at random.

Source: Wood Engineering Handbook, 2021

Equilibrium Moisture Content (EMC)

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

State	City	EMC (%)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Ott	Nov	Dec
AZ	Flagstaff	11.8	11.4	10.8	9.3	8.8	7.5	9.7	11.1	10.3	10.1	10.8	11.8
AZ	Phoenix	9.4	8.4	7.9	6.1	5.1	4.6	6.2	6.9	6.9	7.0	8.2	9.5
AZ	Tucson	9.1	8.3	7.6	6.0	5.2	4.8	7.7	8.8	7.6	7.5	8.0	9.2
AZ	Winslow	12.3	9.9	8.5	7.2	6.2	5.5	8.0	8.7	8.6	8.5	9.8	12.0
AZ	Yuma	8.2	7.8	7.3	6.5	6.1	5.6	6.8	7.4	7.5	7.4	8.0	8.7
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
WI	Green Bay	14.5	14.4	14.3	13.1	12.5	13.0	13.6	14.6	14.8	14.4	15.2	15.5
WI	La Crosse	14.1	14.0	13.8	12.4	12.2	13.0	13.5	14.5	14.7	13.7	14.6	15.2
WI	Madison	14.5	14.3	14.1	12.8	12.5	12.8	13.4	14.4	14.9	14.1	15.2	15.7
WI	Milwaukee	14.0	13.9	13.9	13.4	12.9	13.1	13.4	14.3	14.4	13.8	14.5	15.0

Equilibrium Moisture Content. The moisture content at which wood neither gains nor loses moisture when surrounded by air at a given relative humidity and temperature. - Wood Handbook: Wood as an Engineering Material, 2021

Source: Equilibrium moisture content of wood in outdoor locations in the United States and worldwide. Res. Note FPL-RN-0268. https://www.fs.usda.gov/treesearch/pubs/5913

Equilibrium Moisture Content (EMC) & Relative Humidity

Relative Humidity - Ratio of the amount of water vapor present in the air to that which the air would hold at saturation at the same temperature; Wood Engineering Handbook, 2021

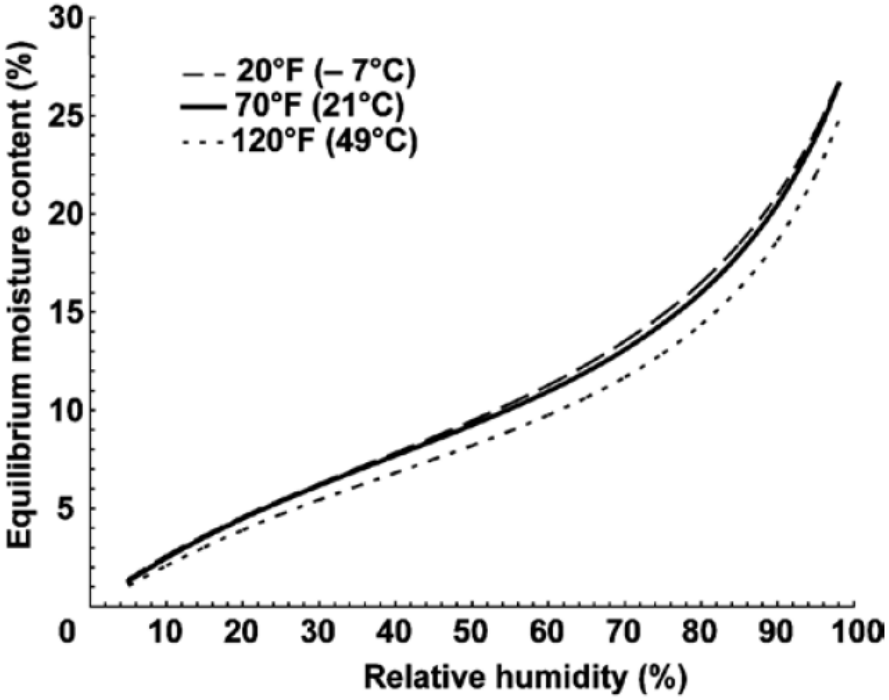
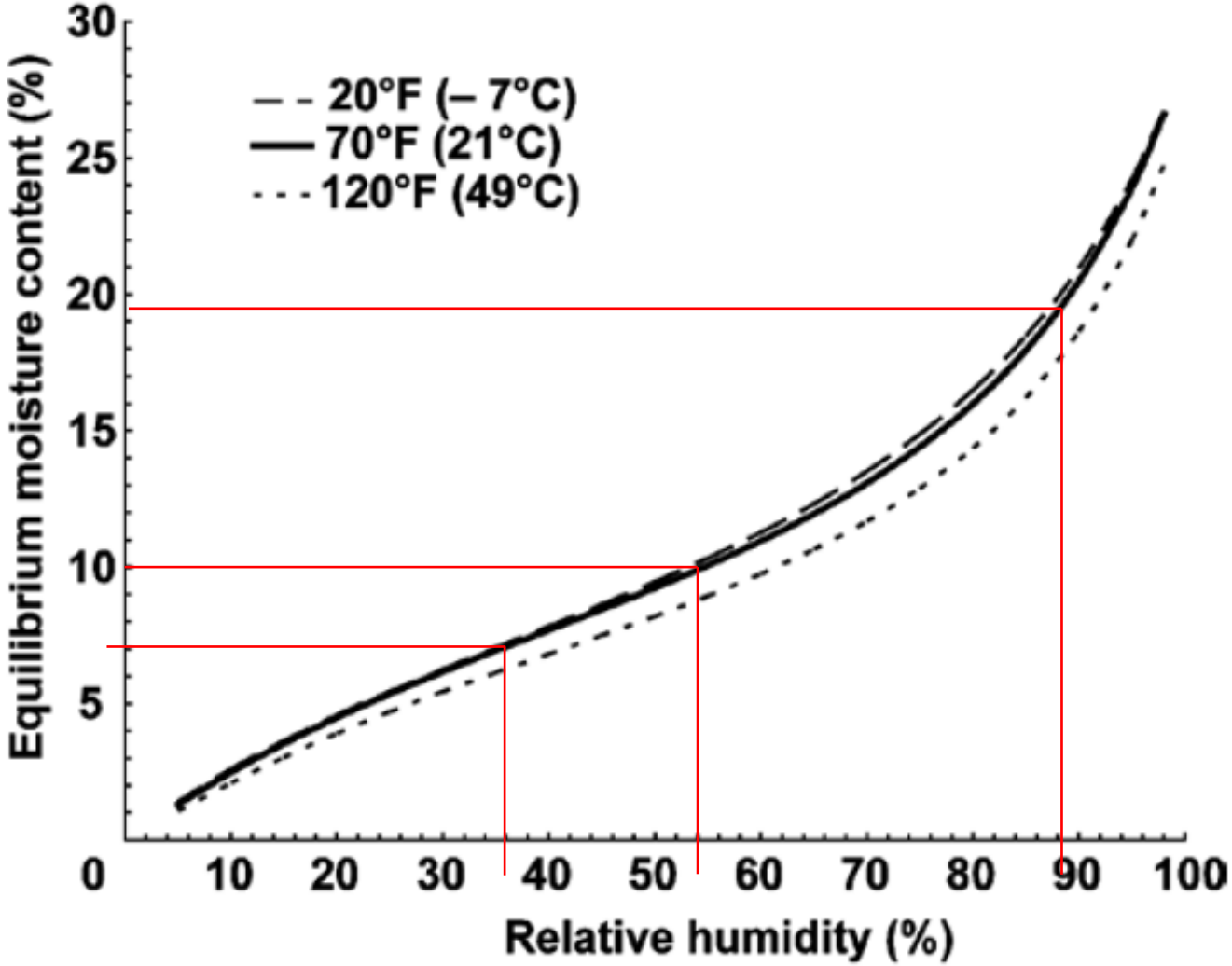


Figure 1—Wood equilibrium moisture content as a function of relative humidity for select temperatures (based on FPL 1999).

Source: Review of in-service moisture and temperature conditions in wood-frame buildings. General Technical Report FPL-GTR-174 http://www.fs.usda.gov/treesearch/pubs/28970



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Source: Review of in-service moisture and temperature conditions in wood-frame buildings. General Technical Report FPL-GTR-174 http://www.fs.usda.gov/treesearch/pubs/28970

Table 4–2. 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													

Source: Wood Engineering Handbook, 2021

Relative Humidity, Dry-Bulb & Wet-Bulb Depression

- **Dry-bulb** - The temperature of the kiln air.
- **Wet-bulb** - The temperatures indicated by any temperature measuring device, the sensitive element of which is covered by a smooth, clean, soft, water-saturated cloth (wet-bulb wick or porous sleeve).
- **Wet-Bulb Depression** – Difference between Dry-Bulb and Wet-Bulb.

Dry Kiln Operators Manual, 1991

Image Source: Conway-Cleveland Corporation
https://www.conwaycleveland.com/kiln-supplies-ovens/hygrometer-60-120f

Table 1-6—Relative humidity and equilibrium moisture content at various dry-bulb temperatures and wet-bulb depressions below 212°F.

Dry-bulb temperature (°F)	Relative humidity[1] and equilibrium moisture content[2] (%) at various wet-bulb depression temperatures (°F)																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
30	89	78	67	57	46	36	27	17	6	—	—	—	—	—	—	—	—	—
	—	*15.9*	*12.9*	*10.8*	*9.0*	*7.4*	*5.7*	*3.9*	*1.6*	—	—	—	—	—	—	—	—	—
35	90	81	72	63	54	45	37	28	19	11	3	—	—	—	—	—	—	—
	—	*16.8*	*13.9*	*11.9*	*10.3*	*8.8*	*7.4*	*6.0*	*4.5*	*2.9*	*0.8*	—	—	—	—	—	—	—
40	92	83	75	68	60	52	45	37	29	22	15	8	—	—	—	—	—	—
	—	*17.6*	*14.8*	*12.9*	*11.2*	*9.9*	*8.6*	*7.4*	*6.2*	*5.0*	*3.5*	*1.9*	—	—	—	—	—	—
45	93	85	78	72	64	58	51	44	37	31	25	19	12	6	—	—	—	—
	—	*18.3*	*15.6*	*13.7*	*12.0*	*10.7*	*9.5*	*8.5*	*7.5*	*6.5*	*5.3*	*4.2*	*2.9*	*1.5*	—	—	—	—
50	93	86	80	74	68	62	56	50	44	38	32	27	21	16	10	5	—	—
	—	*19.0*	*16.3*	*14.4*	*12.7*	*11.5*	*10.3*	*9.4*	*8.5*	*7.6*	*6.7*	*5.7*	*4.8*	*3.9*	*2.8*	*1.5*	—	—
55	94	88	82	76	70	65	60	54	49	44	39	34	28	24	19	14	9	5
	—	*19.5*	*16.9*	*15.1*	*13.4*	*12.2*	*11.0*	*10.1*	*9.3*	*8.4*	*7.6*	*6.8*	*6.0*	*5.3*	*4.5*	*3.6*	*2.5*	*1.3*
60	94	89	83	78	73	68	63	58	53	48	43	39	34	30	26	21	17	13
	—	*19.9*	*17.4*	*15.6*	*13.9*	*12.7*	*11.6*	*10.7*	*9.9*	*9.1*	*8.3*	*7.6*	*6.9*	*6.3*	*5.6*	*4.9*	*4.1*	*3.2*
65	95	90	84	80	75	70	66	61	56	52	48	44	39	36	32	27	24	20
	—	*20.3*	*17.8*	*16.1*	*14.4*	*13.3*	*12.1*	*11.2*	*10.4*	*9.7*	*8.9*	*8.3*	*7.7*	*7.1*	*6.5*	*5.8*	*5.2*	*4.5*
70	95	90	86	81	77	72	68	64	59	55	51	48	44	40	36	33	29	25
	—	*20.6*	*18.2*	*16.5*	*14.9*	*13.7*	*12.5*	*11.6*	*10.9*	*10.1*	*9.4*	*8.8*	*8.3*	*7.7*	*7.2*	*6.6*	*6.0*	*5.5*
75	95	91	86	82	78	74	70	66	62	58	54	51	47	44	41	37	34	31
	—	*20.9*	*18.5*	*16.8*	*15.2*	*14.0*	*12.9*	*12.0*	*11.2*	*10.5*	*9.8*	*9.3*	*8.7*	*8.2*	*7.7*	*7.2*	*6.7*	*6.2*
80	96	91	87	83	79	75	72	68	64	61	57	54	50	47	44	41	38	35
	—	*21.0*	*18.7*	*17.0*	*15.5*	*14.3*	*13.2*	*12.3*	*11.5*	*10.9*	*10.1*	*9.7*	*9.1*	*8.6*	*8.1*	*7.7*	*7.2*	*6.8*
85	96	92	88	84	80	76	73	70	66	63	59	56	53	50	47	44	41	38
	—	*21.2*	*18.8*	*17.2*	*15.7*	*14.5*	*13.5*	*12.5*	*11.8*	*11.2*	*10.5*	*10.0*	*9.5*	*9.0*	*8.5*	*8.1*	*7.6*	*7.2*
90	96	92	89	85	81	78	74	71	68	65	61	58	55	52	49	47	44	41
	—	*21.3*	*18.9*	*17.3*	*15.9*	*14.7*	*13.7*	*12.8*	*12.0*	*11.4*	*10.7*	*10.2*	*9.7*	*9.3*	*8.8*	*8.4*	*8.0*	*7.6*

Relative Humidity (%) not italic
Equilibrium Moisture Content (%) in italic

Source: Dry Kiln Operators Manual, 1991

Table 1-6—Relative humidity and equilibrium moisture content at various dry-bulb temperatures and wet-bulb depressions below 212°F.

Dry-bulb temperature (°F)	Relative humidity[1] and equilibrium moisture content[2] (%) at various wet-bulb depression temperatures (°F)																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
30	89	78	67	57	46	36	27	17	6	—	—	—	—	—	—	—	—	—
	—	*15.9*	*12.9*	*10.8*	*9.0*	*7.4*	*5.7*	*3.9*	*1.6*	—	—	—	—	—	—	—	—	—
35	90	81	72	63	54	45	37	28	19	11	3	—	—	—	—	—	—	—
	—	*16.8*	*13.9*	*11.9*	*10.3*	*8.8*	*7.4*	*6.0*	*4.5*	*2.9*	*0.8*	—	—	—	—	—	—	—
40	92	83	75	68	60	52	45	37	29	22	15	8	—	—	—	—	—	—
	—	*17.6*	*14.8*	*12.9*	*11.2*	*9.9*	*8.6*	*7.4*	*6.2*	*5.0*	*3.5*	*1.9*	—	—	—	—	—	—
45	93	85	78	72	64	58	51	44	37	31	25	19	12	6	—	—	—	—
	—	*18.3*	*15.6*	*13.7*	*12.0*	*10.7*	*9.5*	*8.5*	*7.5*	*6.5*	*5.3*	*4.2*	*2.9*	*1.5*	—	—	—	—
50	93	86	80	74	68	62	56	50	44	38	32	27	21	16	10	5	—	—
	—	*19.0*	*16.3*	*14.4*	*12.7*	*11.5*	*10.3*	*9.4*	*8.5*	*7.6*	*6.7*	*5.7*	*4.8*	*3.9*	*2.8*	*1.5*	—	—
55	94	88	82	76	70	65	60	54	49	44	39	34	28	24	19	14	9	5
	—	*19.5*	*16.9*	*15.1*	*13.4*	*12.2*	*11.0*	*10.1*	*9.3*	*8.4*	*7.6*	*6.8*	*6.0*	*5.3*	*4.5*	*3.6*	*2.5*	*1.3*
60	94	89	83	78	73	68	63	58	53	48	43	39	34	30	26	21	17	13
	—	*19.9*	*17.4*	*15.6*	*13.9*	*12.7*	*11.6*	*10.7*	*9.9*	*9.1*	*8.3*	*7.6*	*6.9*	*6.3*	*5.6*	*4.9*	*4.1*	*3.2*
65	95	90	84	80	75	70	66	61	56	52	48	44	39	36	32	27	24	20
	—	*20.3*	*17.8*	*16.1*	*14.4*	*13.3*	*12.1*	*11.2*	*10.4*	*9.7*	*8.9*	*8.3*	*7.7*	*7.1*	*6.5*	*5.8*	*5.2*	*4.5*
70	95	90	86	81	77	72	68	64	59	55	51	48	44	40	36	33	29	25
	—	*20.6*	*18.2*	*16.5*	*14.9*	*13.7*	*12.5*	*11.6*	*10.9*	*10.1*	*9.4*	*8.8*	*8.3*	*7.7*	*7.2*	*6.6*	*6.0*	*5.5*
75	95	91	86	82	78	74	70	66	62	58	54	51	47	44	41	37	34	31
	—	*20.9*	*18.5*	*16.8*	*15.2*	*14.0*	*12.9*	*12.0*	*11.2*	*10.5*	*9.8*	*9.3*	*8.7*	*8.2*	*7.7*	*7.2*	*6.7*	*6.2*
80	96	91	87	83	79	75	72	68	64	61	57	54	50	47	44	41	38	35
	—	*21.0*	*18.7*	*17.0*	*15.5*	*14.3*	*13.2*	*12.3*	*11.5*	*10.9*	*10.1*	*9.7*	*9.1*	*8.6*	*8.1*	*7.7*	*7.2*	*6.8*
85	96	92	88	84	80	76	73	70	66	63	59	56	53	50	47	44	41	38
	—	*21.2*	*18.8*	*17.2*	*15.7*	*14.5*	*13.5*	*12.5*	*11.8*	*11.2*	*10.5*	*10.0*	*9.5*	*9.0*	*8.5*	*8.1*	*7.6*	*7.2*
90	96	92	89	85	81	78	74	71	68	65	61	58	55	52	49	47	44	41
	—	*21.3*	*18.9*	*17.3*	*15.9*	*14.7*	*13.7*	*12.8*	*12.0*	*11.4*	*10.7*	*10.2*	*9.7*	*9.3*	*8.8*	*8.4*	*8.0*	*7.6*

Relative Humidity (%) not italic
Equilibrium Moisture Content (%) in italic

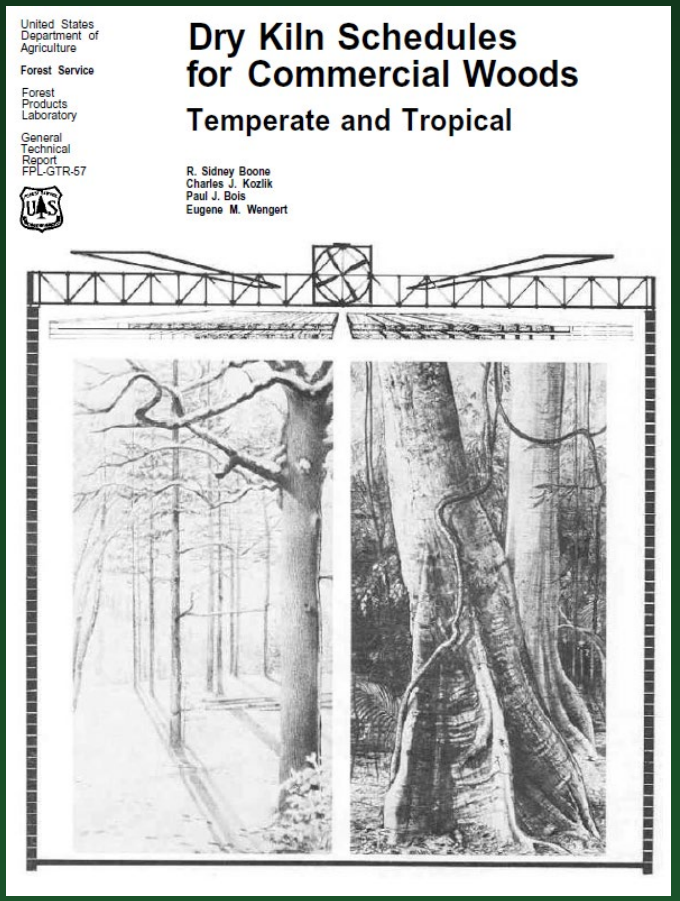
Source: Dry Kiln Operators Manual, 1991

Questions and Discussion

Drying Schedules

Two Types of Dry Kiln Schedules

1. Moisture Content Based
   - ❑ Daily monitoring of moisture content.
   - ❑ Temperature ramp-ups are based upon MC%
   - ❑ In-kiln inspection for surface checking.
   - ❑ Recommended for ponderosa pine (Rappold recommendation).
2. Time Based
   - ❑ Used extensively for Douglas fir stud material.
   - ❑ Temperature ramp-ups based upon time in kiln, time in set point



Stages of Lumber Drying

Table 2.4—Stages of drying

Stage	Wood moisture content[a]	Major defect risk
I	Green to 2/3 green	Formation of surface and end checks, stain, warp
II	2/3 green to 30% MC	Aggravation of surface and end checks
III	30% MC to final	Conversion of checks to honeycomb, cupping, overdrying
IV	Final	Unequal final MC, casehardening

[a]Green denotes moisture content (MC) in the living tree, not when the lumber is received.

Fiber Saturation Point

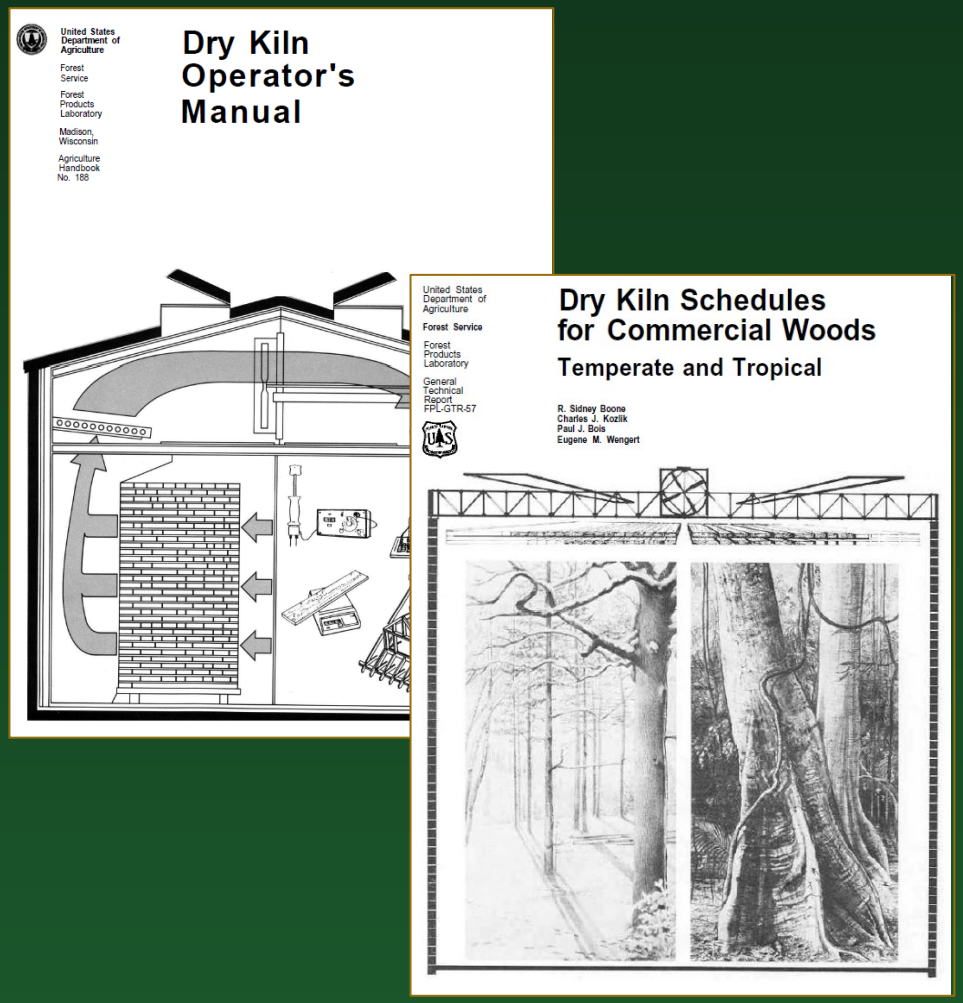
Conditioning & Equalizing

Source: Drying Hardwood Lumber https://www.fpl.fs.fed.us/documnts/fplgtr/fplgtr118.pdf

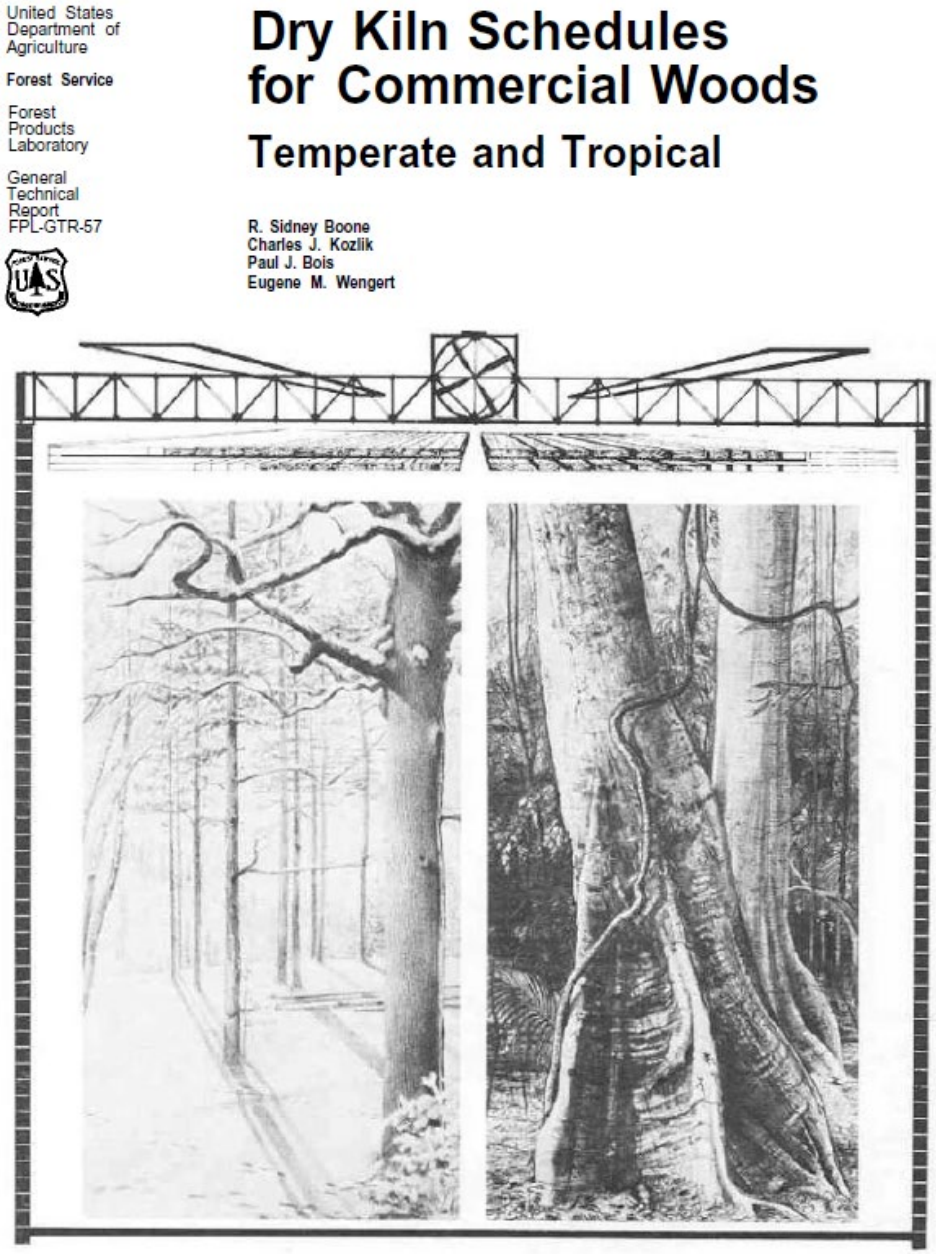
New Dry Kiln and New Drying Schedule

- Ask the manufacturer if they have any schedule recommendations.
- Make sure dry bulb and wet bulb are calibrated.
- Make sure vents are working properly.
- Contact a local wood utilization specialist at a college or state forestry agency.

References to Start Developing Schedules



- The Forest Products Laboratory drying schedules were developed before forest restoration became relevant.
- Realize that your lumber may contain more juvenile wood than Forest Products Laboratory scientists ever imagined.
- Tweak schedule until desired results are obtained.
- Pay attention to daily MC% loss rates.
- Adjust as needed for frozen lumber and customer needs.



Dry kiln schedules for commercial woods : temperate and tropical

R. Sidney Boone
Charles J. Kozlik
Paul J. Bois
Eugene M. Wengert

1988

This report contains suggested dry kiln schedules for over 500 commercial woods, both temperate and tropical. Kiln schedules are completely assembled and written out for easy use. Schedules for several thicknesses and specialty products (e.g. squares, handle stock, gunstock blanks) are given for many species. The majority of the schedules are from the world literature, with emphasis on U.S., Canadian, and British publications. Revised schedules have been suggested for western U.S. and Canadian softwoods and for the U.S. southern pines. Current thinking on high- temperature drying (temperatures exceeding (212 °F) schedules for both softwoods and hardwoods is reflected in suggested high-temperature schedules for selected species.

https://www.fpl.fs.fed.us/documnts/fplgtr/fplgtr57.pdf

Index of Schedules for Kiln-Drying United States and Canadian Softwood Species at Conventional Temperatures
A. Moisture Content-Controlled Schedules[1]

Common name (botanical name)	4/4, 5/4 stock	6/4 stock	8/4 stock	10/4 stock	12/4 stock	British Schedule[2] 4/4 stock	Comments
	- - - - - - - - - - *Table number (schedule code)*[3] - - - - - - - - - -						
Baldcypress *(Taxodium distichum)*	269 (T12-E3)	–	257 (T11-D2)	231 (T8-A4)	231 (T8-A4)	K	
Cedar							
Alaska yellow *(Chamaecyparis nootkatensis)*	261 (T12-A3)	–	248 (T11-A2)	–	–	J	
Atlantic white *(Chamaecyparis thyoides)*	262 (T12-A4)	–	249 (T11-A3)	–	–	–	
eastern redcedar *(Juniperus virginiana)*	206 (T5-A4)	–	205 (T5-A3)	–	–	–	
incense *(Libocedrus decurrens)*	253 (T1-B5)	–	242 (T10-B4)	–	–	–	
northern white *(Thuja occidentalis)*	264 (T12-84)	–	251 (T11-B3)	–	–	–	
Port Orford *(Chamaecyparis lawsoniana)*	252 (T11-64)	–	241 (T10-B3)	–	–	–	
western redcedar *(Thuja plicata)*							
light	243 (T10-B5)	–	241 (T10-B3)	–	–	J	
heavy	216 (T5-F4)	–	215 (T5-F3)	–	–	–	
Douglas-fir, coast *(Pseudotsuga menziesii)*	250 (T11-A4)	–	240 (T10-A3)	203 (T5-A1)	203 (T5-A1)	K	
Fir							
balsam *(Abies balsamea)*	270 (T12-E5)	–	247 (T10-E4)	231 (T8-A4)	231 (T8-A4)	L	
California red *(A. magnifica)*	270 (T12-E5)	–	247 (T10-E4)	230 (T8-A3)	230 (T8-A3)	–	
grand *(A. grandis)*	270 (T12-E5)	–	247 (T10-E4)	231 (T8-A4)	230 (T8-A3)	–	
noble *(A. procera)*	263 (T12-A5)	250 (T11-A4)	240 (T10-A3)	204 (T5-A2)	204 (T5-A2)	–	
Pacific silver *(A. amabilis)*	265 (T12-B5)	–	241 (T10-B3)	–	–	–	
subalpine *(A. lasiocarpa)*	265 (T12-B5)	–	264 (T12-B4)	–	–	–	
white *(A. concolor)*	270 (T12-E5)	260 (T11-D5)	247 (T10-E4)	231 (T8-A4)	231 (T8-A4)	–	
Hemlock							
eastern *(Tsuga canadensis* and *T. caroliniana)*	266 (T12-C4)	–	254 (T11-C3)	230 (T8-A3)	229 (T8-A2)	K	
western *(Tsuga mertensiana* and *T. heterophylla)*	267 (T12-C5)	256 (T11-C5)	255 (T11-C4)	231 (T8-A4)	230 (T8-A3)	K	
Larch, western *(Larix occidentalis)*	235 (T9-B4)	223 (T7-C4)	222 (T7-C3)	220 (T7-A3)	219 (T7-A2)	–	
Pine							
eastern white *(Pinus strobus)*							
standard	256 (T11-C5)	–	244 (T10-C4)	244 (T10-C4)	232 (T8-C3)	L	16/4, use table 208 (T5-C2). Northeastern Regional Schedule; for 4/4-6/4, use table 310; for 8/4, use table 311.
anti brown-stain	276	–	277	–	278	–	
lodgepole *(Pinus contorta)*	244 (T10-C4)	–	236 (T9-C3)	–	–	L	
ponderosa *(Pinus ponderosa)*							
standard	238 (T9-C6)	225 (T7-C6)	224 (T7-C5)	221 (T7-A4)	221 (T7-A4)	L	
antibrown-stain	228 (T7-E6)	–	227 (T7-E5)	–	–	–	
red or Norway *(Pinus resinosa)*	264 (T12-B4)	–	251 (T11-B3)	220 (T7-A3)	220 (T7-A3)	L	

Source: Dry kiln schedules for commercial woods : temperate and tropical, 1988

Schedule T9-C6 Ponderosa Pine

Table 238 **T9-C6S**

Step	Moisture content	Temperature Dry-bulb	Temperature Wet-bulb	Equilibrium moisture content	Relative humidity	Temperature Dry-bulb	Temperature Wet-bulb
	pct	- - - - - - °F - - - - - -		- - - - - - *pct* - - - - - -		- - - - - - °C - - - - - -	
1	Above 40	140	125	9.6	64	60.0	51.5
2	40 to 35	140	120	8.0	55	60.0	49.0
3	35 to 30	140	115	6.8	46	60.0	46.0
4	30 to 25	150	120	5.8	41	65.5	49.0
5	25 to 20	160	125	5.1	37	71.0	51.5
6	20 to 15	160	125	5.1	37	71.0	51.5
7	15 to Final	160	110	3.4	21	71.0	43.5

Equalize and condition as necessary (see appendix A).

Source: Dry kiln schedules for commercial woods : temperate and tropical, 1988

Understanding the Numbering of Schedule T9-C6

- T9 – Dry Bulb Temperature
- C – Moisture Content Class
- 6 – Wet Bulb Depression Class

❖ Large initial wet bulb depressions equate to more aggressive drying rates.

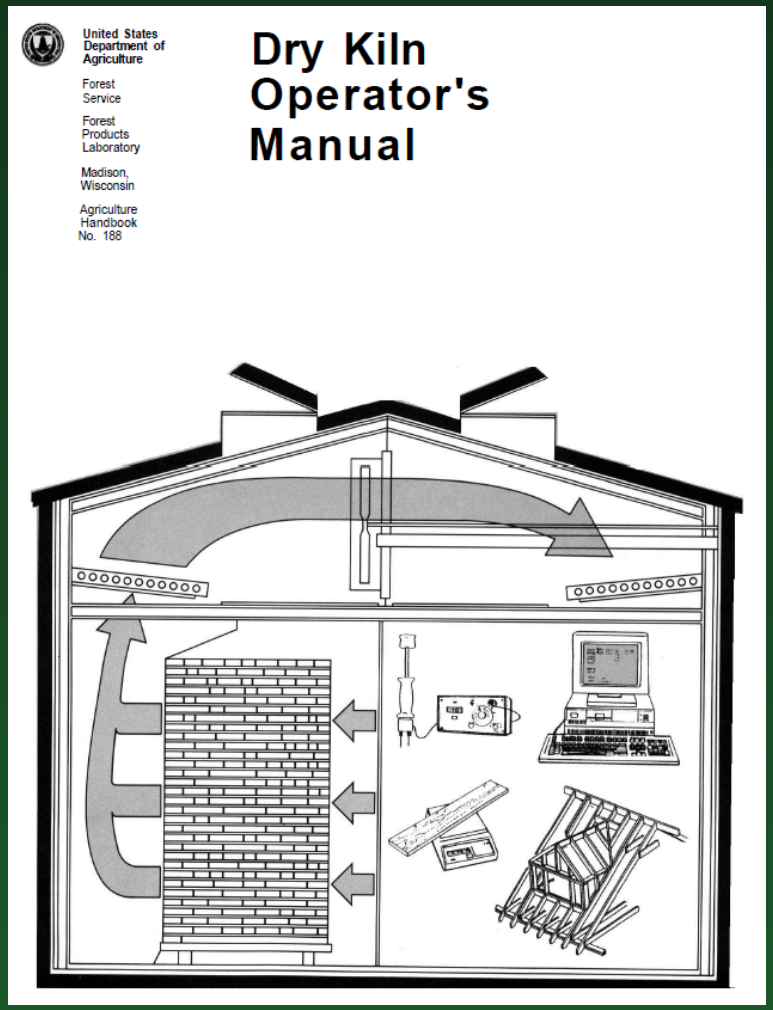


Table 7-15—Moisture content schedules for softwoods

Dry-bulb temperature step no.	Moisture content at start of step (percent)	Dry-bulb temperatures (°F) for various temperature schedules													
		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T 1 3	T 1 4
1	>30	100	100	110	110	120	120	130	130	140	140	150	160	170	180
2	30	105	110	120	120	130	130	140	140	150	150	160	170	180	190
3	25	105	120	130	130	140	140	150	150	160	160	160	170	180	190
4	20	115	130	140	140	150	150	160	160	160	170	170	180	190	200
5	15	120	150	160	180	160	180	160	180	160	180	180	180	190	200

Table7-16—Moisture content wet-bulb depression schedules for softwoods

Wet-bulb depression step no.	Moisture content (percent) at start of step for various moisture content classes						Wet-bulb depressions (°F) for various wet-bulb depression schedules							
	A	B	C	D	E	F	1	2	3	4	5	6	7	8
1	>30	>35	>40	>50	>60	>70	3	4	5	7	10	15	20	25
2	30	35	40	50	60	70	4	5	7	10	14	20	25	30
3	25	30	35	40	50	60	6	8	11	15	20	25	30	35
4	20	25	30	35	40	50	10	14	15	20	25	30	35	35
5	(1)	20	25	30	35	40	15	20	20	25	30	35	35	35
6	—	(1)	20	25	30	35	20	25	25	30	35	35	35	35
7	—	—	(1)	20	25	30	25	30	30	35	35	35	35	35
8	—	—	—	(1)	20	25	30	35	35	35	35	35	35	35

T9-C6

Schedule T9-C6 Ponderosa Pine

Table 238 **T9-C6S**

Step	Moisture content	Temperature Dry-bulb	Temperature Wet-bulb	Equilibrium moisture content	Relative humidity	Temperature Dry-bulb	Temperature Wet-bulb
	pct	- - - - - - °F - - - - - -		- - - - - - *pct* - - - - - -		- - - - - - °C - - - - - -	
1	Above 40	140	125	9.6	64	60.0	51.5
2	40 to 35	140	120	8.0	55	60.0	49.0
3	35 to 30	140	115	6.8	46	60.0	46.0
4	30 to 25	150	120	5.8	41	65.5	49.0
5	25 to 20	160	125	5.1	37	71.0	51.5
6	20 to 15	160	125	5.1	37	71.0	51.5
7	15 to Final	160	110	3.4	21	71.0	43.5

Equalize and condition as necessary (see appendix A).

Source: Dry kiln schedules for commercial woods : temperate and tropical, 1988

Table 7-17—Code number index of moisture content schedules[1] recommended for kiln drying 4/4, 6/4, and 8/4 softwood lumber

Species	Schedules for lower grades[2]			Schedules for upper grades'		
	4/4	6/4	8/4	4/4	6/4	8/4
Baldcypress	—	—	—	T12-E3	—	T11-D2
Cedar						
Alaska	—	—	—	T12-A3	—	T11-A2
Atlantic white	—	—	—	T12-A4	—	T11-A3
Eastern redcedar	—	—	—	T5-A4	—	T5-A3
Incense	—	—	—	T11-B5	—	T10-B4
Northern white	—	—	—	T12-B4	—	T11-B3
Port-Orford	—	—	—	T11-B4	—	T10-B3
western redcedar						
Light	T9-A6	—	—	T10-B5	—	T10-B3
Heavy	—	—	—	T5-F4	—	T5-F3
Douglas-fir						
coast region	T7-A4	—	[3]T7-A4	T11-A4	—	T10-A3
Inland region	[4]T9-A4	—	[4]T9-A4	—	—	—
Fir						
Balsam	—	—	—	T12-E5	—	T10-E4
California red	—	—	—	T12-E5	—	T10-E4
Grand	—	—	—	T12-E5	—	T10-E4
Noble	—	—	—	T12-A5	T11-A4	T10-A3
Pacific silver	—	—	—	T12-B5	—	T10-B3
Subalpine	—	—	—	T12-B5	—	T12-B
White	T9-D6	—	T9-D5	T12-E5	T11-E5	T10-E4
Hemlock						
Eastern	—	—	—	T12-C4	—	T11-C3
Western	[3]T11-E5	—	T11-E5	T12-C5	T11-C5	T11-C4
Larch	[4]T7-C5	—	[3]T7-C5	T9-B4	T7-C4	T7-C3
Pine						
Eastern white						
Regular	T9-C5	—	T9-C4	T11-C5	—	T10-C4
Jack	T9-C4	—	T9-C3	—	—	—
Lodgepole	T5-C5	—	—	T10-C4	—	T9-C3
Ponderosa						
Heartwood	T9-A6	T7-A6	T5-A5	—	—	—
Sapwood	T11-C7	—	—	T9-C6	T7-C5	T7-C5
Antibrown-stain	—	—	—	T7-E6	—	T7-E5
Red	—	—	—	T12-B4	—	T11-B3
Southern yellow	T12-C5	—	—	T13-C6	T12-C5	T12-C5
sugar						
Light	T9-E7	T7-E6	—	T5-E6	T5-E6	T5-E5
Heavy	—	—	—	T5-F6	T5-F6	T5-F5
Western white						
Regular	T9-C6	—	[4]T7-C6	T9-C5	T7-C5	T7-C4
water core	T9-E6	—	—	—	—	—
Redwood						
Light	—	—	—	T5-D6	—	T5-D4
Heavy	—	—	—	T4-F5	T3-F5	T3-F4
Spruce						
Eastern (black, red, white)	—	—	—	T11-B4	—	T10-B3
Englemann	T7-B6	T5-B5	[3]T5-B5	T9-E5	—	T7-E4
Sitka	T7-A5	—	—	T12-B5	T12-B4	T11-B3
Tamarack	—	—	—	T11-B3	—	T10-B3

[1]Schedules are given in tables 7-20 and 7-21.
[2]Lower grades include commons, dimension, and box; upper grades include clears, selects, shop, and factory; also tight-knotted paneling.
[3]Maximum wet-bulb depression 25 °F.
[4]Maximum wet-bulb depression 20 °F.

Source: Dry Kiln Operators Manual, 1991

Table 7-15—Moisture content schedules for softwoods

Dry-bulb temperature step no.	Moisture content at start of step (percent)	Dry-bulb temperatures (°F) for various temperature schedules													
		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T 1 3	T 1 4
1	>30	100	100	110	110	120	120	130	130	140	140	150	160	170	180
2	30	105	110	120	120	130	130	140	140	150	150	160	170	180	190
3	25	105	120	130	130	140	140	150	150	160	160	160	170	180	190
4	20	115	130	140	140	150	150	160	160	160	170	170	180	190	200
5	15	120	150	160	180	160	180	160	180	160	180	180	180	190	200

T9-A6

Table7-16—Moisture content wet-bulb depression schedules for softwoods

Wet-bulb depression step no.	Moisture content (percent) at start of step for various moisture content classes						Wet-bulb depressions (°F) for various wet-bulb depression schedules							
	A	B	C	D	E	F	1	2	3	4	5	6	7	8
1	>30	>35	>40	>50	>60	>70	3	4	5	7	10	15	20	25
2	30	35	40	50	60	70	4	5	7	10	14	20	25	30
3	25	30	35	40	50	60	6	8	11	15	20	25	30	35
4	20	25	30	35	40	50	10	14	15	20	25	30	35	35
5	(1)	20	25	30	35	40	15	20	20	25	30	35	35	35
6	—	(1)	20	25	30	35	20	25	25	30	35	35	35	35
7	—	—	(1)	20	25	30	25	30	30	35	35	35	35	35
8	—	—	—	(1)	20	25	30	35	35	35	35	35	35	35

Table 238 **Schedule T9-C6** T9-C6S

Step	Moisture content	Temperature Dry-bulb	Temperature Wet-bulb	Equilibrium moisture content	Relative humidity	Temperature Dry-bulb	Temperature Wet-bulb
	pct	------ °F ------		------ *pct* ------		------ °C ------	
1	Above 40	140	125	9.6	64	60.0	51.5
2	40 to 35	140	120	8.0	55	60.0	49.0
3	35 to 30	140	115	6.8	46	60.0	46.0
4	30 to 25	150	120	5.8	41	65.5	49.0
5	25 to 20	160	125	5.1	37	71.0	51.5
6	20 to 15	160	125	5.1	37	71.0	51.5
7	15 to Final	160	110	3.4	21	71.0	43.5

Equalize and condition as necessary (see appendix A).

Schedule T9-A6

Step	Moisture Content	Dry-bulb	Wet-bulb Depression	Wet-bulb	Equilibrium MC	Relative Humidity
	%	------ °F ------			---- % ----	
1	Above 30	140	15	125	9.6	64
2	30 to 25	150	20	130	8.0	57
3	25 to 20	160	25	135	6.8	50
4	20 to 15	160	30	130	5.8	43
5	15 to Final	160	35	125	5.2	38
Equalize and Condition						

Ramping Up Temperatures to Set Points from a Cold Start

- Increase dry bulb temperatures at a rate that will not overwhelm your fuel system.
- Increase dry bulb temperature 5 - 10°F per hour to set point.
- Utilize the ability to open and close vents when needed.

Equalizing, Conditioning, Setting the Pitch

Equalizing

- Bring all lumber pieces to nearly equal moisture content. Accomplished by introducing water vapor into the dry kiln.
- Begin equalizing when the driest sample is 3 percent below the final target MC and continue until the wettest piece has dried to the target MC.

Conditioning

- Relief of drying stresses. Accomplished by introducing water vapor into the dry kiln.
- A high dry bulb temperature (170°F), high relative humidity treatment to create uniform distribution of moisture from the core to the shell.
- May require long periods of time to achieve desired conditions. Large capacity dry kilns may require up to 12 hours of continuous conditioning treatment.

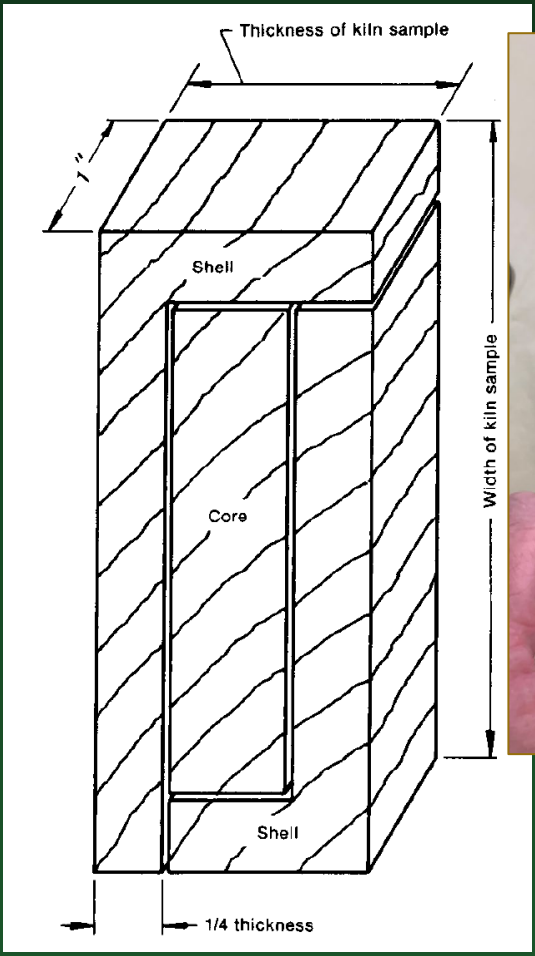
Setting the Pitch

- Goal is to drive off turpentine and other naturally occurring solvents. For ponderosa pine, this is typically done at the end of the drying cycle and is usually accomplished as part of the conditioning treatment. Target dry bulb temperature is +160°F.
- Only required for softwood lumber species.

These are the most frequently overlooked components of kiln drying lumber

Dry Kiln Operators Manual, 1991

Conditioning Relieves Drying Stresses



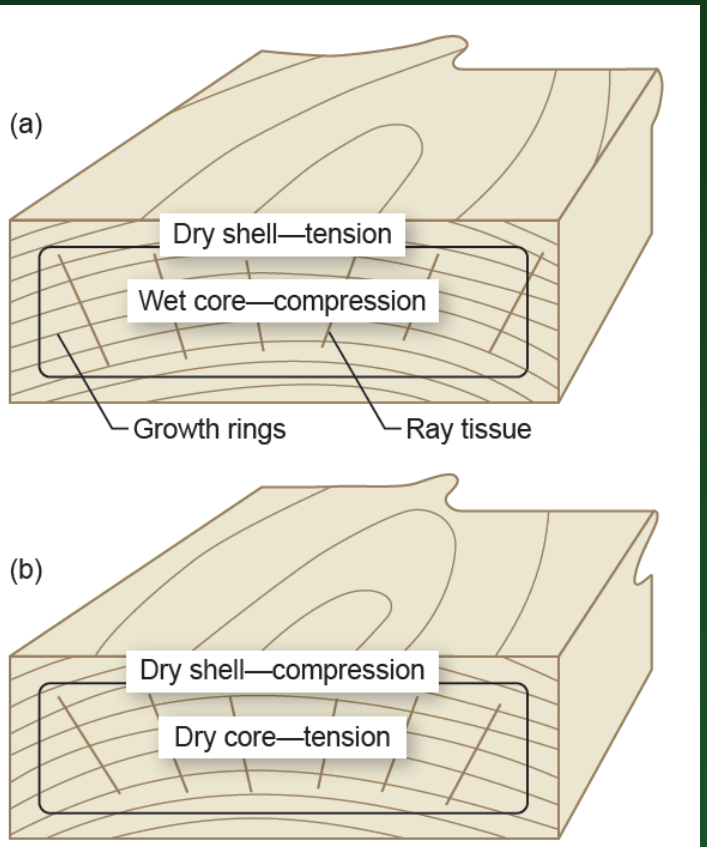


Figure 13–3. End view of board showing development of drying stresses (a) early and (b) later in drying.

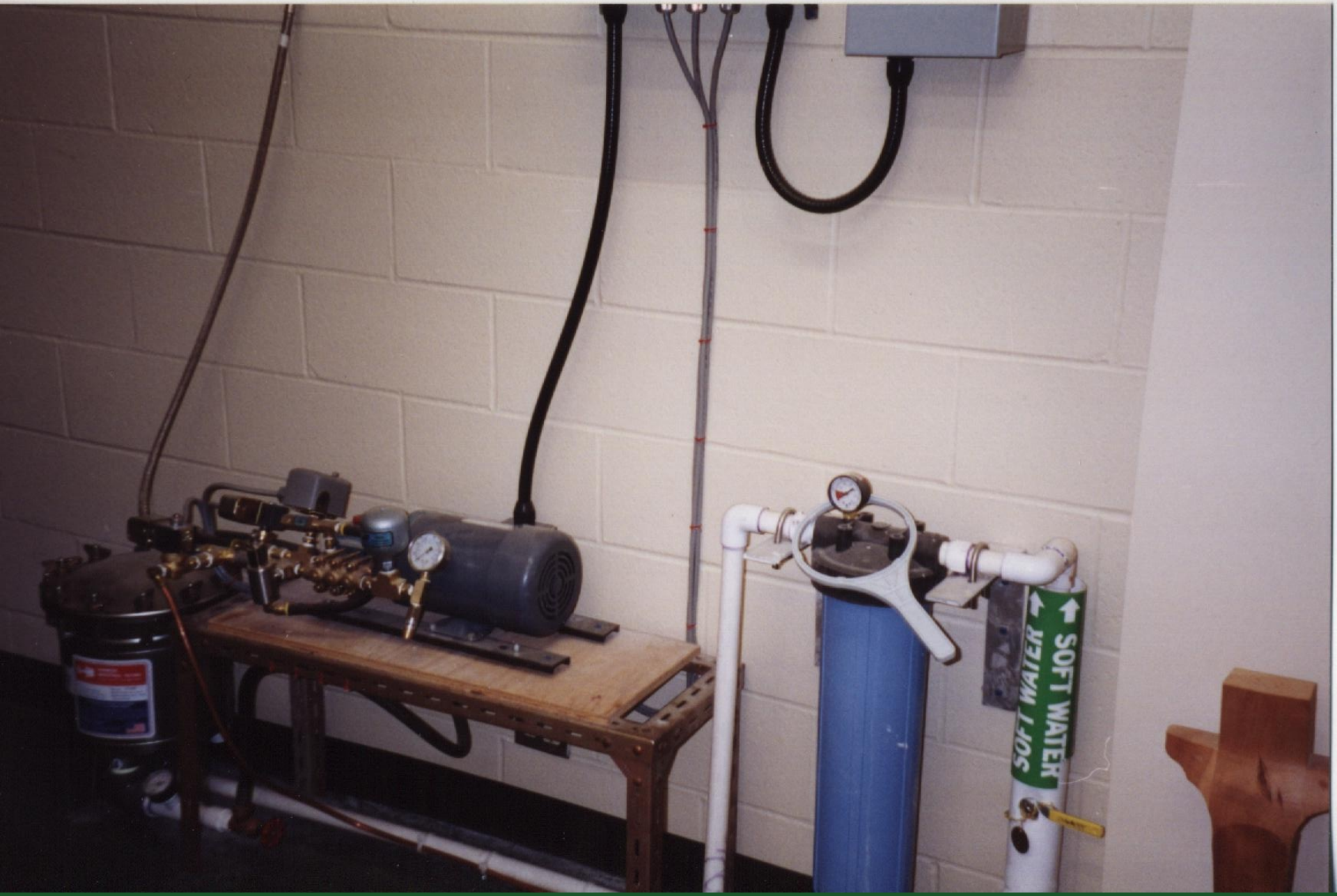
Conditioning and Equalizing Strategies

Table 7-32—Kiln sample moisture content and equilibrium moisture content values for equalizing and conditioning a charge of lumber

Desired final average) moisture content (percent)	Equalizing moisture content values (percent)			Conditioning equilibrium moisture content values (percent)	
	Moisture content of driest sample at start	Equilibrium moisture content conditions in kiln	Moisture content of wettest sample at end	Softwoods	Hardwoods
5	3	3	5	8	9
6	4	4	6	9	10
7	5	5	7	10	11
8	6	6	8	11	12
9	7	7	9	12	13
10	8	8	10	13	14
11	9	9	11	14	15

Source: Dry Kiln Operators Manual, 1991

Spray Lines


SOFT WATER
SOFT WATER

What About Dehumidification Units?

Industrial Garment Steamer

Evaluating the Conditioning Treatment

Figure 11-22. Stress or casehardening test in kiln-dried lumber. Prong tests in the top row show no stress. The two samples on the bottom left show casehardened lumber, while the two on the right show reverse casehardening.

Manufacturing and Marketing Eastern Hardwood Lumber Produced by Thin Kerf Band Mills; https://www.kansasforests.org/forest_products/forest_product_docs/Manufacturing-marketing-thin-kerf.pdf

Evaluating the Conditioning Treatment

Photocopy the Stress Test and the Kiln Chart for Record Keeping Purposes

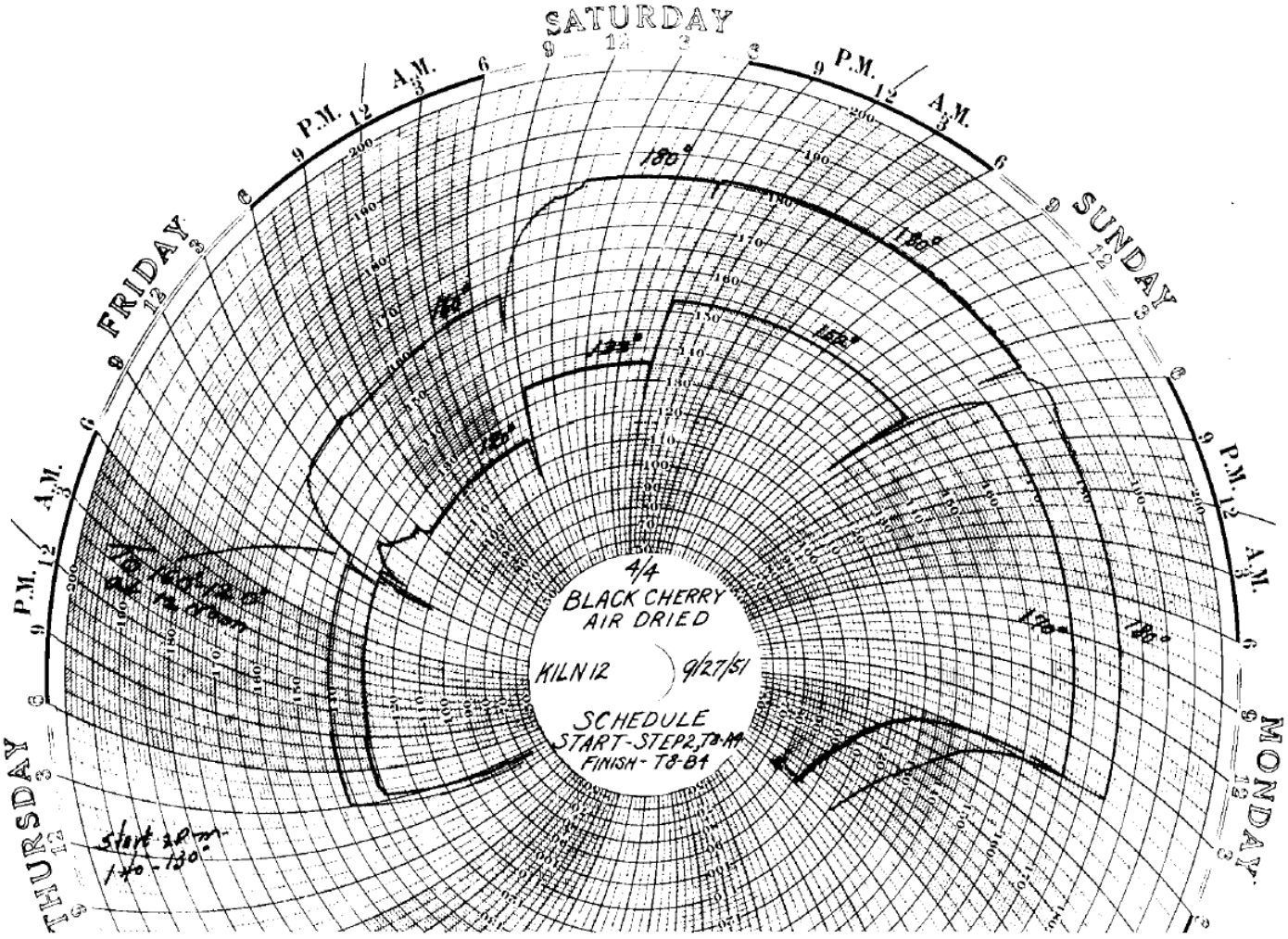


Figure 12.—Instrument chart of conditions used in kiln drying a small load of air-dried black cherry. (Assumed to have undergone surface moisture regain.)

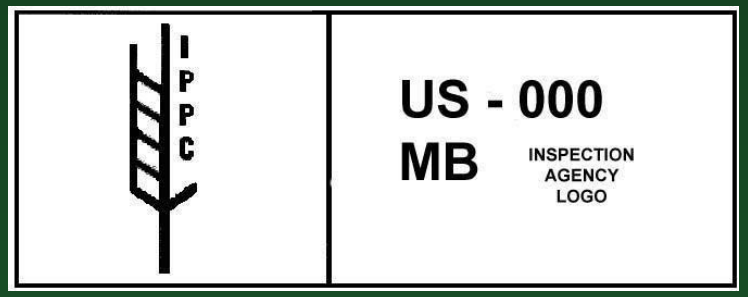
Source: Drying Eastern Hardwood Lumber https://www.fpl.fs.fed.us/documnts/usda/ah528.pdf

Phytosanitation

International Standards For Phytosanitary Measures No. 15 (ISPM 15) - Regulation of Wood Packaging Material in International Trade

USDA United States Department of Agriculture
Animal and Plant Health Inspection Service

https://www.aphis.usda.gov/aphis/home



ISPM -15
Phytosanitation Treatments

Heat Treatment

Heat treated at a core temperature of 132.8°F for a minimum of 30 minutes.

- Temperature can be measured by inserting temperature sensors in the core of the wood.
- If measuring core temperature is not possible – standard treatment schedules can be developed based upon verified testing.

Methyl Bromide

Retain Kiln Chart for Record Keeping Purposes

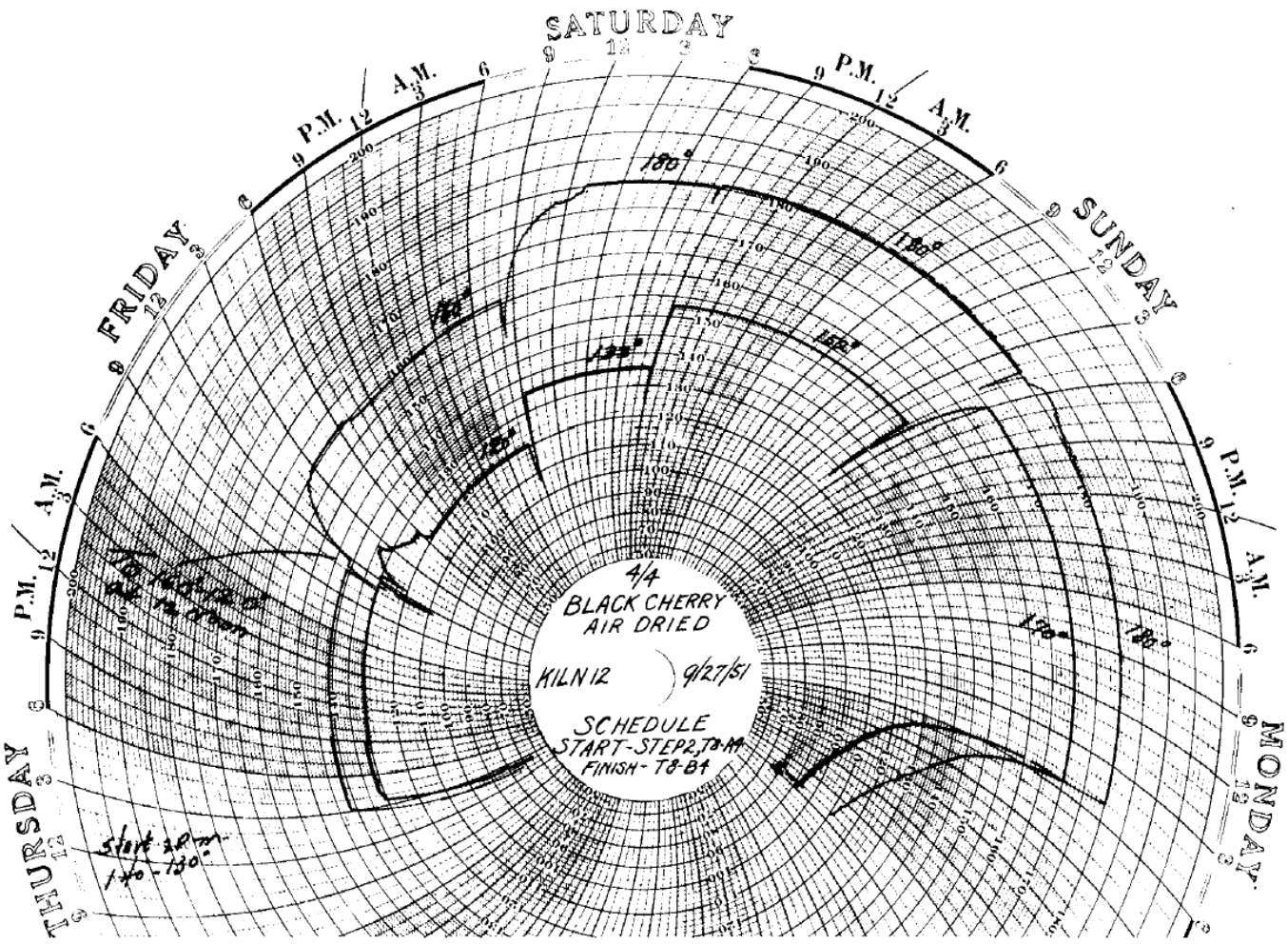
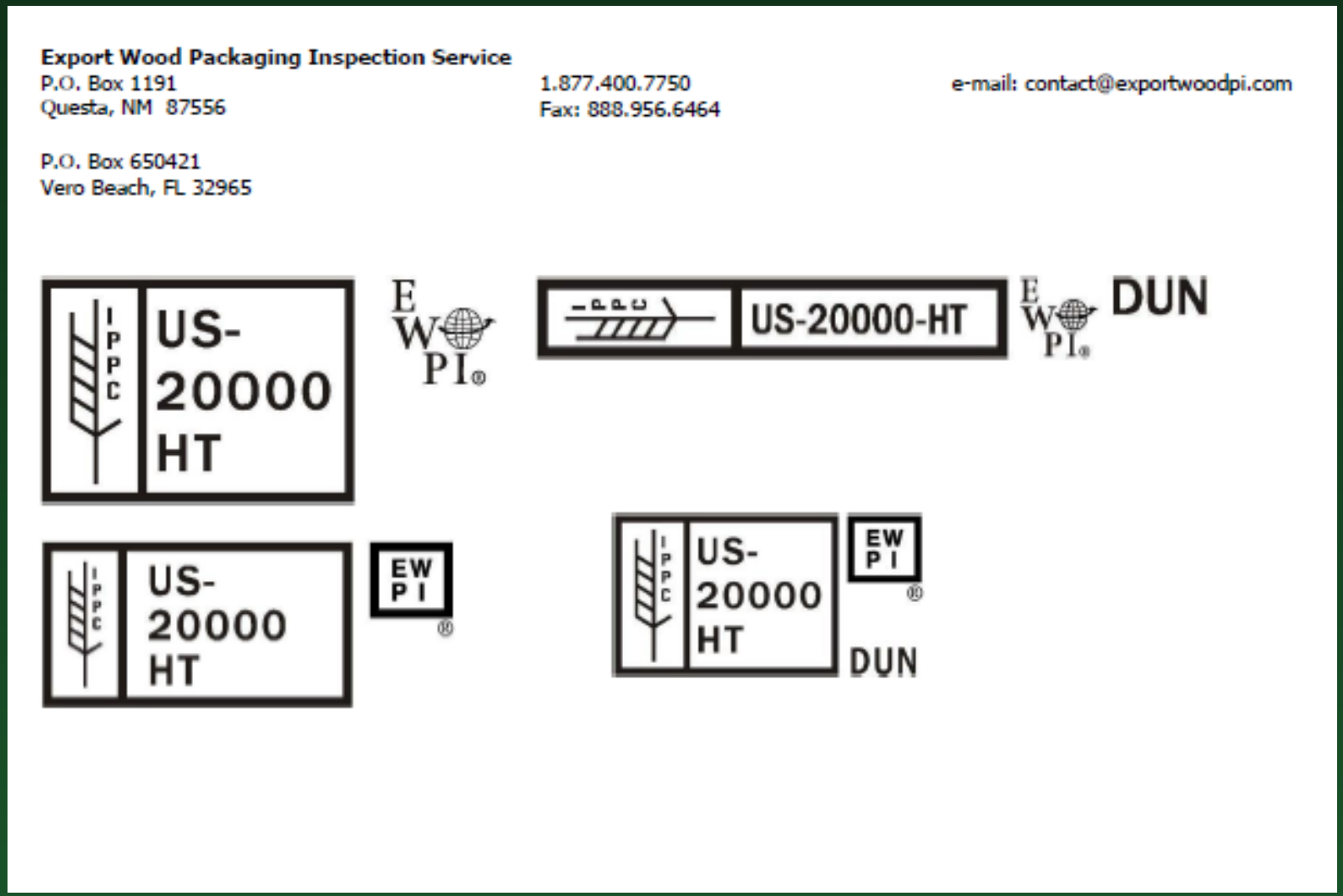


Figure 12.—Instrument chart of conditions used in kiln drying a small load of air-dried black cherry. (Assumed to have undergone surface moisture regain.)

Source: Drying Eastern Hardwood Lumber https://www.fpl.fs.fed.us/documnts/usda/ah528.pdf

Retain Kiln Data for Record Keeping Purposes

Heat Treatment Stamps



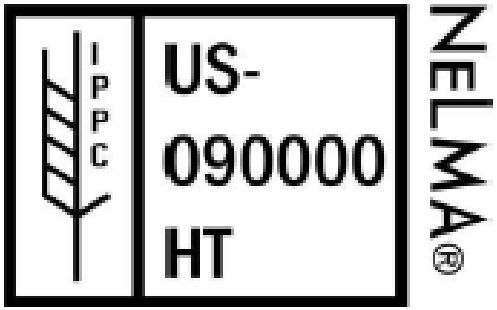
American Lumber Standard Committee, Incorporated http://www.alsc.org/

Heat Treatment Stamps

Northeastern Lumber Manufacturers Association
272 Tuttle Road, P.O. Box 87A
Cumberland Center, ME 04021

207.829.6901
Fax: 207.829.4293

e-mail: info@nelma.org



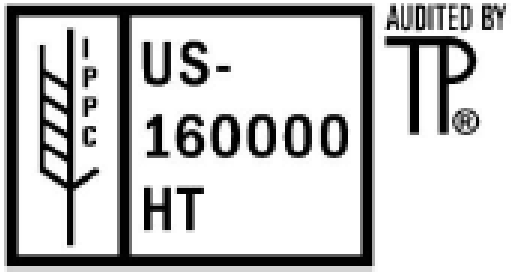
American Lumber Standard Committee, Incorporated http://www.alsc.org/

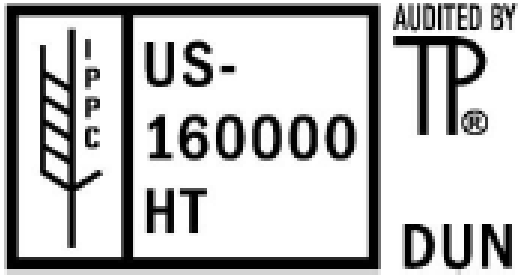
Heat Treatment Stamps

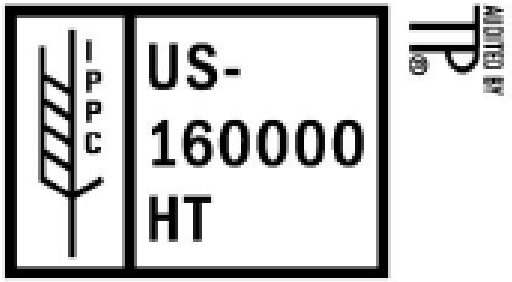
Timber Products Inspection
100 Kedron Dr.
Peachtree City, GA 30269

770.922.8000
Fax: 770.922.1290

e-mail: mmcgowan@tpinspection.com







American Lumber Standard Committee, Incorporated http://www.alsc.org/

Heat Treatment Stamps

Western Wood Products Association
1500 SW First Avenue, Suite 870
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503.224.3930
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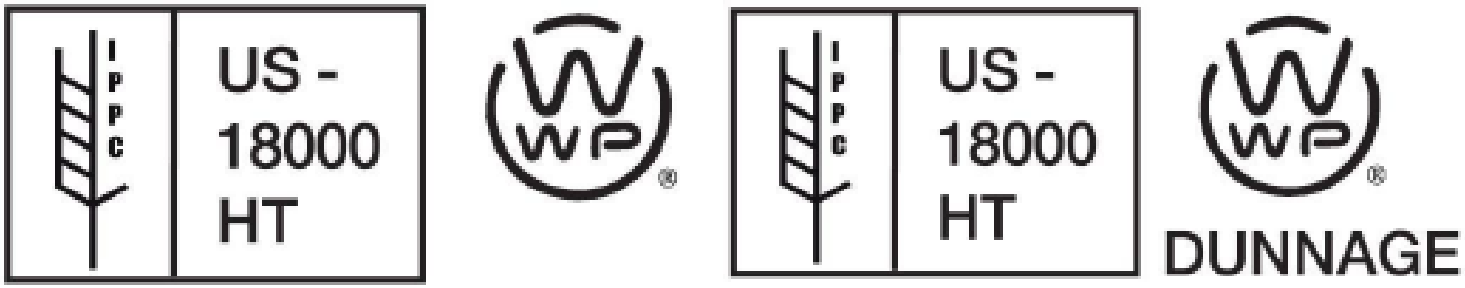
e-mail: info@wwpa.org



American Lumber Standard Committee, Incorporated http://www.alsc.org/

Bark

Use of debarked wood

Irrespective of the type of treatment applied, wood packaging material must be made of debarked wood. For this standard, any number of visually separate and clearly distinct small pieces of bark may remain if they are:

- less than 3 cm in width (regardless of the length) or
- greater than 3 cm in width, with the total surface area of an individual piece of bark less than 50 square cm.

For methyl bromide treatment, the removal of bark must be carried out before treatment as the presence of bark on the wood may affect treatment efficacy. For heat treatment, the removal of bark may be carried out before or after treatment. When a dimension limitation is specified for a certain type of heat treatment (e.g. dielectric heating), any bark must be included in the dimension measurement.

ISPM -15
https://www.ippc.int/static/media/files/publications/en/2014/06/30/ispm_15_2009_en_2014-06-16.pdf

Methyl Bromide Fumigation Tents

Image: USDA APHIS

Methyl Bromide Fumigation Tents

Image: USDA APHIS

Questions and Discussion