

Dehumidification Drying for Small Woodworking Firms and Hobbyists

Building Your Own Lumber Dry Kiln with Local Building Materials



Authored By:
Scott Bowe, Patrick Molzahn, Brian Bond,
Richard Bergman, Terry Mace, and Steve Hubbard

Introduction

In recent years, we have received hundreds of requests for small scale lumber dry kiln plans from woodworking hobbyists. People were looking for an inexpensive and simple kiln design that could cost effectively dry as little as a few hundred board feet of lumber or as much as several thousand board feet of lumber each year. There are many different kiln designs including solar, dehumidification, direct or indirect fired, and vacuum kilns. For small operations, there is a large amount of information available on solar kiln design and operation. However, solar lumber kilns are not effective for large portions of the calendar year in northern climates (due to cold winter temperatures).

Our goal was to develop a small scale kiln that produced quality kiln dried lumber, was functional throughout the year, was reasonably inexpensive to build, and was constructed with common building materials from the local lumber yard and hardware store. With these constraints in mind, we chose simple 2" x 6" construction to build the drying chamber and powered it with a common basement dehumidifier, electric heater, and four attic fans.

This publication outlines the basic construction of a small scale dehumidification dry kiln. When properly loaded, this kiln can dry approximately 600 board feet of 4/4" lumber. This plan allows for flexibility in the design of the kiln. The kiln volume can be modified to custom fit the individual's needs. As with any value adding opportunity (including wood drying), outcomes can never be guaranteed. It is highly recommended that users of this publication seek basic training in lumber dry kiln operation. Mistakes can be both costly and frustrating. Sources of additional information are listed at the end of this publication.

Materials List and Building Plans

The following section includes a materials list, the basic kiln plans, and the basic electrical considerations for building the dehumidification dry kiln.

Please refer to Appendix A which shows the Lumber Dry Kiln Bill of Materials. All of these products were purchased at a local home center, except the remote

hygrometer/thermometer which was purchased at a local electronics store. Total costs for the materials were \$2,704 based on 2006 prices.

Appendix B illustrates the kiln construction layout including a plan view, section view, front elevation, back elevation, and detailed illustrations of the door sections. These drawings are not to scale (see Appendix B1-B6).

The floor system was framed using 2" x 8" construction 16 inches on center (see plan Appendix B1). Three-quarter inch CDX plywood was used for the inside floor. One-half inch pressure treated plywood was used to close the underside of the floor system. Pressure treated plywood is recommended since the bottom of the kiln may be in moist conditions if stored outside. If stored outside, place on skids to raise the kiln off of the ground. The floor system was insulated with rigid foam insulation cut to fit between the 2" x 8" joists. A plastic vapor barrier could be used under the three-quarter plywood floor; however, rigid foam acts as its own vapor barrier.

The side and rear wall systems were framed using 2" x 6" construction 16 inches on center (see section and back elevation Appendix A). One-half inch CDX plywood was used for the inside wall sheathing and three-quarter inch T-111 plywood siding was used on the exterior walls. The walls were insulated with R-19 fiberglass batts. A plastic vapor barrier was used between the inside wall sheathing and wall studs (see Figure 1).



Figure 1: A plastic vapor barrier was used between the inside wall sheathing and wall studs.

The door side of the kiln was framed using 2" x 4" construction (see Appendix B3: Front Elevation and Appendix B5: Door Details). The doors were designed to be removed in a three-panel system. Doors of this size are difficult to hinge without sagging, so removable panels were a suitable alternative (see Figure 2). The door system was insulated with rigid foam insulation cut to fit between the 2" x 4" members. One-half inch CDX plywood was used for the inside door sheathing and one-half inch T-111 plywood siding was used on the exterior of the door panels. An access door was added on the back kiln wall to allow access to the dehumidifier and electronic equipment (see Appendix B4: Back Elevation). This prevented the need for opening the main door section and crawling over the lumber pile when access was needed to the dehumidifier.



Figure 2: Removable panel doors.

The roof system was framed using 2" x 6" rafters 16 inches on center (see Appendix B2-B4). One-half inch CDX plywood was used for both the interior and exterior sheathing. The roof system was insulated with R-19 fiberglass batts. A plastic vapor barrier was used between the inside sheathing and roof rafters. The roof system was covered with standard roofing felt and fiberglass shingles (see Figure 3). Aluminum fascia and plywood soffit was used to finish the roof system.



Figure 3: The kiln roof system was designed for outdoor use.

A baffle system was hung from the roof system down to the top level of the lumber charge. The baffle consisted of 2" x 4" construction with one-half inch CDX sheathing and was hinged at the top using standard door hinges. The baffle served as a platform to mount the four whole house attic fan units which circulate air (see Figure 4). In addition, the baffle controlled the airflow within the kiln which forced air through the lumber charge. Initially, two attic fans were installed with resulting air speeds of 220 cubic feet per minute which was not sufficient for white woods such as maple or basswood. Two more fans were added in the final design which produced air speeds in excess of 400 cubic feet per minute. These fans were wired to allow either two or four fan operation.



Figure 4: The hinged baffle houses the four fans and controls the airflow.

Standard hardware used for the framing included 16d and 8d nails. Stainless steel screws should be used to fasten the interior sheathing given the extremely corrosive nature of a dry kiln environment. In addition, it is important to use stainless steel fasteners which come in contact with pressure treated wood. ACQ pressure treated wood is extremely corrosive on non-coated and galvanized fasteners. These fasteners can fail in as little as one year.

Other hardware included slide bolts, handles, and weather stripping for the doors. Again, stainless steel would be preferred in any applications that come into close contact with the inside kiln environment.

Miscellaneous materials included an exterior grade stain for the kiln siding and paint for the interior walls and floor sheathing.

Electronic Equipment

Relative humidity, air speed, and temperature are the main factors to consider for successful lumber drying. Each of these factors and the appropriate monitoring equipment is discussed in the following paragraphs.

A standard household dehumidifier was used to control the relative humidity within the kiln. Water was carried through a drain hose from the dehumidifier through a hole in the rear wall into a measuring bucket. Measuring the amount of water removed over a given period of time is useful in determining the rate of moisture loss in the lumber charge. Early in the drying process, the dehumidifier controls did not allow for a high enough relative humidity setting and too much water was removed from the charge. To alleviate this problem, the dehumidifier was plugged into a simple lamp timer which cycled the dehumidifier on and off to slow the rate of moisture removal. Different timing sequences are required for different species and thicknesses to achieve a safe allowable moisture removal rate (see Figure 7). Alternatively, the dehumidifier could have been plugged into and controlled by a simple humidistat. These humidistats have a wider relative humidity control range.

A hinged baffle system was hung from the roof system down to the top level of the lumber charge. This system housed the attic fan units and was hinged to swing up and out of the way while loading the kiln.



Figure 5: Heater, measuring bucket, and dehumidifier with lamp timer.

An electric space heater was added to the kiln to boost the operating temperature later in the drying process. During test runs, the space heater was not turned on since the heat generated by the dehumidifier's compressor combined with the heat from the four fan motors was sufficient to reach the required drying temperatures. If the kiln were located outside of a heated building in the winter months, the electric heater would likely be needed to reach desired temperatures (see Figure 5).

A simple remote hygrometer/thermometer purchased at a local electronics store allows the kiln operator to read the interior relative humidity and temperature without entering the kiln. This device consists of a measuring probe and a wireless output screen which can be



Figure 6: Hygrometer/thermometer.

mounted onto the outside of the kiln or anywhere within range of the kiln probe. It is recommended that a Lithium-ion battery be used in exterior, cold-weather applications (see Figure 6).



Lessons Learned

As mentioned earlier, stainless steel fasteners and hardware should be used. Failure to use stainless steel will result in premature failure of the hardware and the potential for stained or discolored lumber. Alternative construction materials for some portions of the current design may be more desirable. One example would be to use impermeable wall insulation such as a spray applied closed cell foam system to limit in-wall moisture penetration. Moisture loss through the kiln structure was noticed at the end of the drying cycle as the lumber moisture content continued to decrease but no condensate was collected from the dehumidifier.

As constructed, the kiln doors are large and heavy. One alternative is to buy or build a structurally insulated panel. These panels consist of rigid foam sandwiched between two sheets of a wood panel product such as plywood or oriented strand board. This design would make a much lighter door panel and provide superior insulation.

A combination of the rapid moisture loss driven by the dehumidifier and the high air speeds driven by the four fan units can overwhelm the novice dry kiln operator. Limiting the run time of the dehumidifier and reducing the fan operation to two fans will make the kiln more forgiving for the novice operator.

Basic Operation of a Lumber Dry Kiln

WARNING

Although lumber drying is a very simple process, it requires constant monitoring and detailed record keeping to produce a quality product. Expensive grade lumber can quickly be destroyed beyond use by extensive drying defects (e.g., checking, honeycomb, end split, etc.). We strongly recommend that you read additional kiln operation materials such as the *Dry Kiln Operator's Manual* listed at the end of this publication. In addition, several kiln operator training courses are offered in the eastern, western, and central United States.

PREPARING THE LUMBER

End coat the green lumber with a commercial end coating immediately after sawing to prevent large losses from end checks and splits. End coating is less effective when applied after the lumber has begun to dry. The end coated lumber should then be stacked in the kiln with approximately 12 inches of clearance on the front side of the stack and approximately 30 inches of clearance on the rear side of the stack (dehumidifier side) to permit adequate air circulation. These spaces are known as plenum spaces. Arrange the lumber in neat layers, separated by stickers or spacers running perpendicular to the lumber's length. The lumber in each layer must be uniform in thickness. If the sawn lumber is quite variable in thickness, one or both faces of the boards should be planed before drying to obtain a uniform thickness. This will reduce warping during drying. Particularly in warmer months, green lumber should be stacked with stickers quickly after sawing or it may begin to develop stain – an undesirable and highly visual defect.

Stickers used between each layer of wood are typically three-quarter inch thick, one-and-one-quarter inches wide, and as long as the lumber pile is wide. It is important that stickers are uniform in thickness and kept dry. Stickers are placed perpendicular to the boards' length, every 12 to 18 inches along the pile's length. The stickers are placed directly above the stickers in the lower layers. If the lumber is of varying lengths, shorter boards are staggered by alternating them from one end to the other with the longest pieces always on the outside edges. The ends of every board should be supported with a sticker. Stickers hold the lumber flat, preventing warp, while also allowing air to circulate through the pile and dry the lumber.

While the lumber is being stacked or prior to loading the kiln with pre-stacked lumber, several sample boards must be cut (see Appendix C: Procedures for Cutting and Using Sample Boards). Periodically checking these sample boards will allow you to determine the moisture content of the lumber in the kiln and to observe possible drying defects.

MONITORING THE DRYING PROCESS

While the kiln described in this publication is designed for simple operation, you will still need to closely monitor the drying process. Monitoring the moisture loss and quality of the wood during the drying process will help you maximize the efficiency of the kiln. Simply explained, when drying lumber you want to dry fast enough to prevent stain and long drying times, yet slow enough to prevent checks and other drying defects. The prevalence of certain defects is influenced by the species, thickness, moisture content, and drying conditions.

Monitoring the moisture content during the drying process is important to avoid drying too rapidly (which results in quality loss) and to know when the load has reached the desired moisture content. Measure the sample boards daily to determine the daily rate of moisture loss. This loss should be compared with the safe drying rate for that species (see Figure 7 for hardwoods). If the drying rate is too fast, then it may be necessary to increase the relative humidity setpoint of the dehumidifier or turn two of the four fans off.

Lumber should be dried to the maximum safe drying rate without exceeding the daily loss. The safe drying rate refers to the moisture loss in one day, not the average loss over several days. Figure 7 lists the safe drying rate for common one inch thick North American hardwoods. Softwoods are typically able to dry at a much faster rate and moisture content losses above 10 percent per day are quite common.

When lumber is at its highest moisture content, it is important to adhere to the safe drying rate. Most unwanted checking and splitting in drying lumber occurs as the wood loses the first one-third of its moisture content. Once the lumber dries below 22 percent moisture content, the risk of creating new cracks and splits is low. Dry lumber for interior use to a moisture content of six to eight percent for most areas of the country. This will limit the amount of dimensional changes that would occur when the wood is processed and in service. Lumber used for exterior purposes is usually dried to 12 to 15 percent moisture content. Softwood lumber used for framing is commercially dried to 19 percent moisture content. However, fewer building defects would result if softwood framing lumber were dried down to 12 percent moisture content.

For information on drying schedules and schedules for specific species and thicknesses, see the reference to the *Dry Kiln Operator's Manual* and the *Dry Kiln Schedules for Commercial Woods: Temperate and Tropical*.

In measuring the rates of moisture loss, it is impractical to weigh every board in the kiln and electric meters are not accurate above 30 percent moisture content. Therefore, the sample board method should be used to determine the moisture content of lumber in the kiln. This method uses short, carefully chosen sample boards sawn from larger pieces of lumber and these sample boards are weighed periodically and estimated moistures are calculated. Since the wettest or slowest drying lumber in the kiln has the highest risk of splitting and cracking, the sample boards should represent this kind of lumber. Use samples from the most recently cut wood, the widest and thickest boards, lumber with the most heartwood, and boards that are quartersawn whenever possible (see Appendix C: Procedures for Cutting and Using Sample Boards).

SPECIES	MAXIMUM RATE OF MC LOSS PER DAY (%)	
	1" Thick	2" Thick
Ash, White	10.4	4.1
Beech	4.5	1.8
Birch, Yellow	6.1	2.4
Cherry	5.8	2.3
Elm, American	10.4	4.1
Gum, Red	5.3	2.1
Maple, Hard	6.5	2.6
Maple, Soft (Sapwood)	13.8	5.5
Oak, Red Lowland	1.0 - 2.5	-
Oak, Red Upland	3.8	1.5
Oak, White Upland	2.5	1.0
Poplar, Yellow	13.8	5.5
Tupelo (Black Gum)	10.9	4.3
Walnut	8.2	5.5

Figure 7: Safe Drying Rates for North American Hardwoods.

Additional Web-based References

LUMBER DRYING MANUALS

The following publications can be downloaded free of charge from www.fpl.fs.fed.us:

Simpson, W. T., ed. 1991. Dry Kiln Operator's Manual. United States Department of Agriculture. Forest Service. Forest Products Laboratory. Madison, WI. www.fpl.fs.fed.us/documnts/usda/ah188/ah188.htm

Denig, J., E. M. Wengert, and W. T. Simpson. 2000. Drying Hardwood Lumber. United States Department of Agriculture. Forest Service. Forest Products Laboratory. General Technical Report. FPL-GTR-118. www.fpl.fs.fed.us/documnts/fplgtr/fplgtr118.pdf

Boone, R., C. J. Kozlik, P. J. Bois, and E. M. Wengert. 1993. Dry Kiln Schedules for Commercial Woods: Temperate and Tropical. United States Department of Agriculture. Forest Service. Forest Products Laboratory. Madison, WI. www.fpl.fs.fed.us/documnts/fplgtr/fplgtr57.pdf

Forest Products Laboratory. Air Drying of Lumber. United States Department of Agriculture. Forest Service. Forest Products Laboratory. General Technical Report. FPL-GTR-117. www.fpl.fs.fed.us/documnts/fplgtr/fplgtr117.pdf

WEB RESOURCES

Department of Forest Ecology and Management, University of Wisconsin, Madison, WI
<http://forest.wisc.edu/>

Department of Wood Science and Forest Products, Virginia Tech, Blacksburg, VA
www.woodscience.vt.edu/

United States Department of Agriculture Forest Service Forest Products Laboratory, Madison, WI
www.fpl.fs.fed.us/

Acknowledgements

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Disclaimer

Commercial products named in this publication are for informational purposes only. The authors do not endorse these products and do not intend discrimination against other products which may also be suitable.

Authors

SCOTT BOWE

Associate Professor and Wood Specialist
University of Wisconsin-Madison, Madison WI

PATRICK MOLZAHN

Cabinetmaking and Millwork Program Director
Madison Area Technical College, Madison WI

BRIAN BOND

Associate Professor
Department of Wood Science & Forest Products,
Virginia Tech, Blacksburg VA

RICHARD BERGMAN

Drying Specialist
United States Department of Agriculture Forest Service
Forest Products Laboratory, Madison WI

TERRY MACE

Forest Products Utilization and Marketing Specialist
Wisconsin Department of Natural Resources - Division
of Forestry, Madison WI

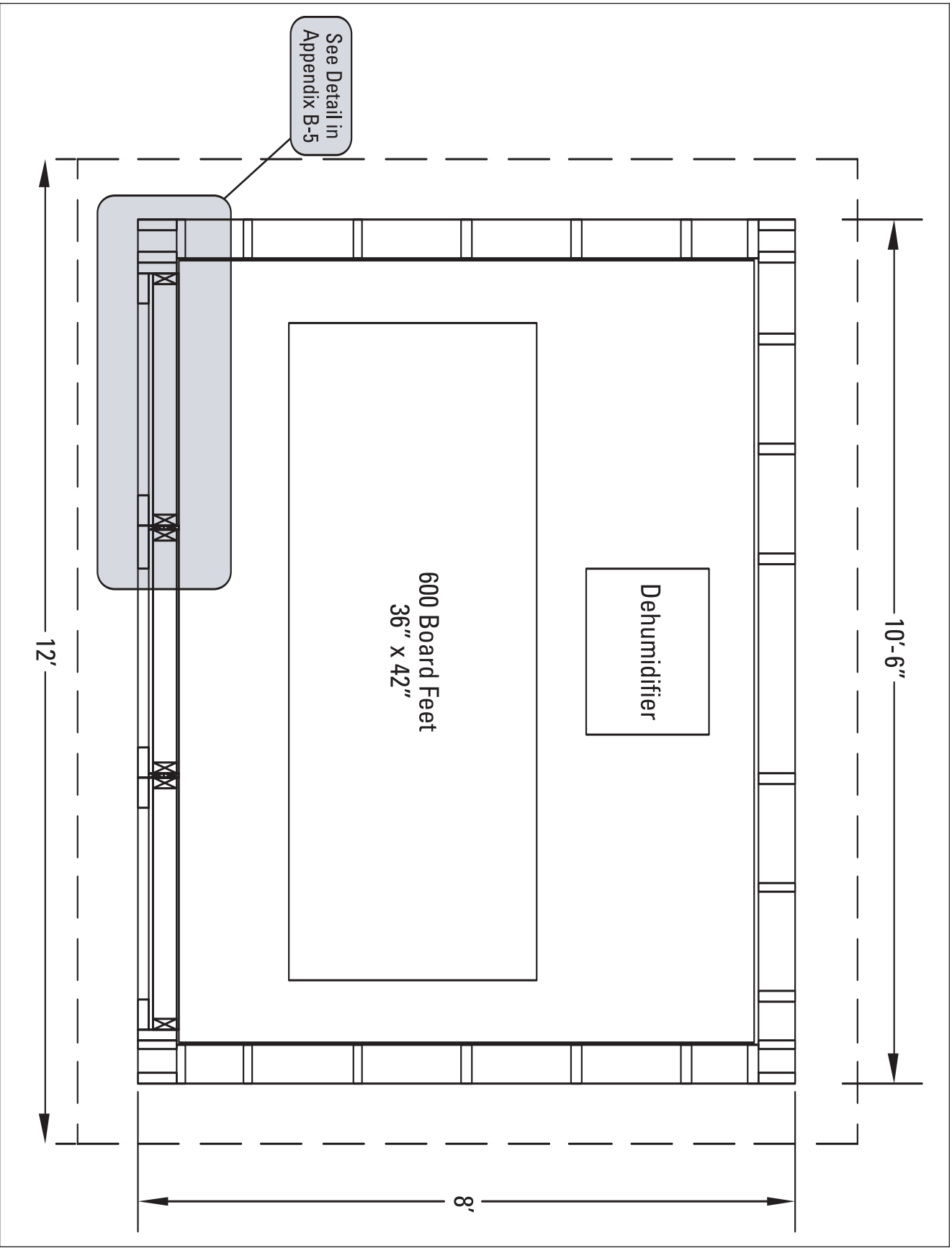
STEVE HUBBARD

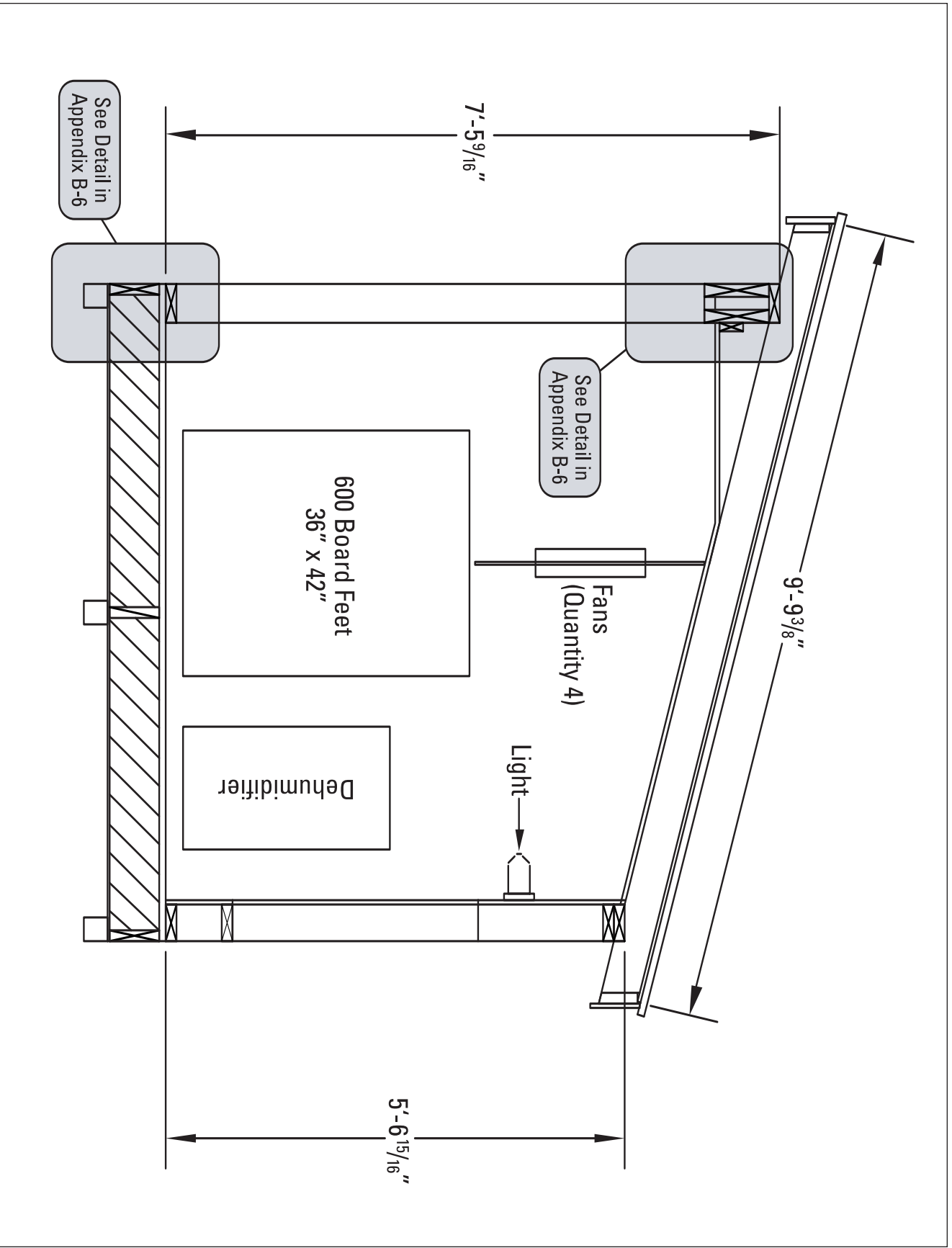
Wood Consultant
Hubbard Forest Solutions, LLC, Madison WI

APPENDIX A: Lumber Dry Kiln Bill of Materials

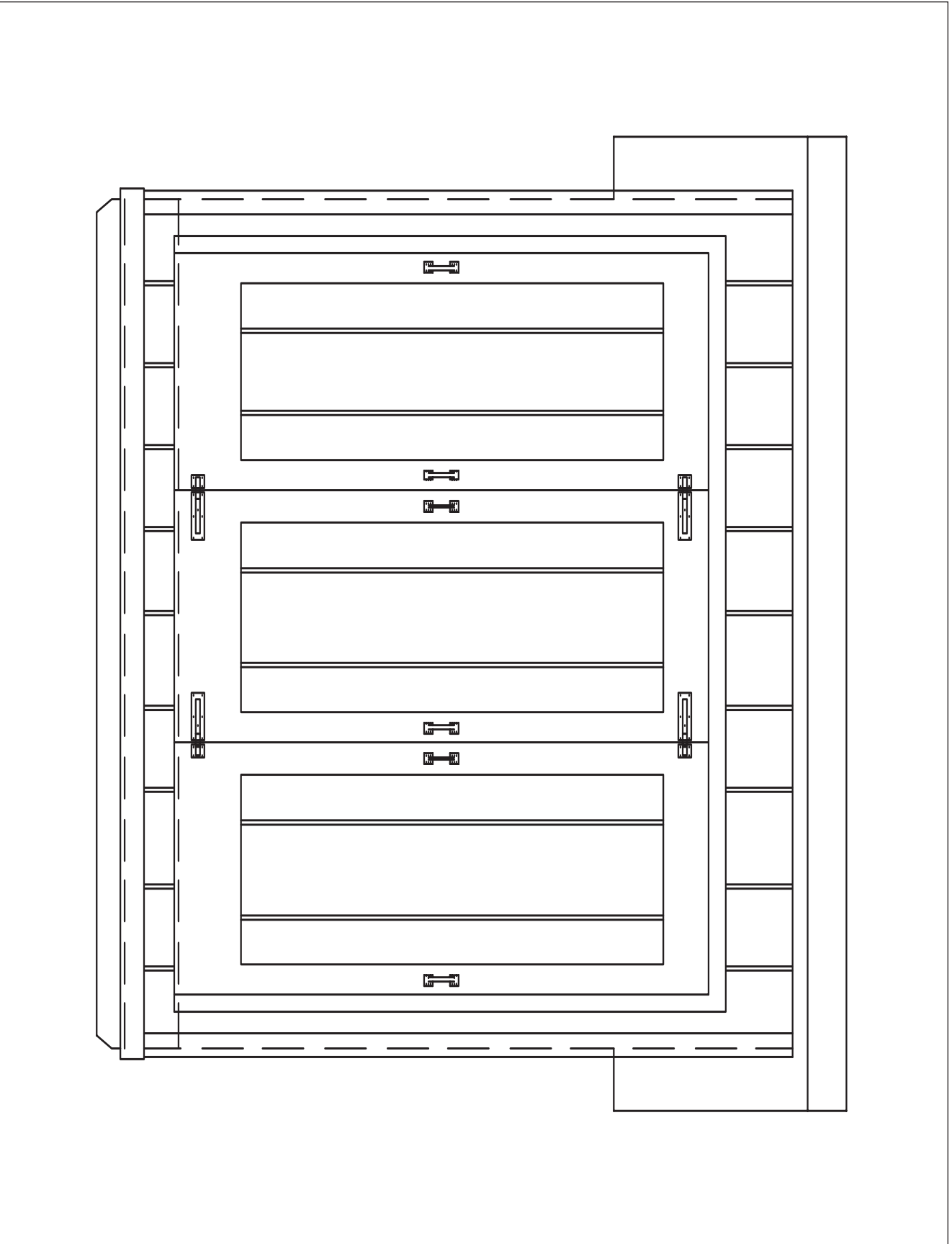
	ITEM	MATERIAL	QUANTITY	COST/UNIT	TOTAL COST
DECK	Runners	4" x 4" x 12' TTD	2	\$11.16	\$22.32
	Floor	1/2" x 4" x 8' TTD Plywood	3	\$32.84	\$98.52
	Floor	3/4" x 4" x 8' CDX	3	\$28.86	\$86.04
	Rim Joists	2" x 8" x 12'	2	\$11.77	\$23.54
	Center Blocking	2" x 8" x 8'	1	\$7.96	\$7.96
	Rim Joists	2" x 8" x 8'	2	\$7.96	\$15.92
	Joists	2" x 8" x 8'	7	\$7.96	\$55.72
	Insulation	2" x 4" x 8' Rigid Foam	8	\$19.89	\$159.12
	Insulation	1" x 4" x 8' Rigid Foam	3	\$9.45	\$28.35
WALLS	Studs	2" x 6" x 92-5/8"	30	\$5.92	\$177.60
	Plates	2" x 6" x 92-5/8"	6	\$5.92	\$35.52
	Plates	2" x 6" x 12'	5	\$8.81	\$44.05
	Header	9-1/2" LVL (LF)	20	\$3.09	\$61.80
	Insulation	R-19 Fiberglass Batt (150 SF)	3	\$14.99	\$44.97
	Interior Sheathing	1/2" x 4" x 8" CDX	8	\$21.01	\$168.08
	Siding	1/2" x 4" x 8" T-111	10	\$37.53	\$375.30
	Sill Sealer	50' Roll	1	\$3.60	\$3.60
	Corners	1" x 4" x 8'	8	\$3.36	\$26.88
	"Z" Flashing	1-1/4" x 10'	5	\$2.26	\$11.30
	Water Table	2" x 4" x 10'	4	\$3.73	\$14.92
	Vapor Barrier	Roll	1	\$12.99	\$12.99
	DOORS	Frames	2" x 4" x 8' SPF	9	\$2.98
Face Moulding		1" x 4" x 8' SPF	10	\$3.36	\$33.60
Insulation		Rigid Foam	4	\$14.65	\$58.60
Casing		1" x 4" x 8' SPF	8	\$3.36	\$26.88
ROOF	Rafters	2" x 6" x 10'	7	\$7.93	\$55.51
	Sub-fascia	2" x 6" x 12'	2	\$8.81	\$17.62
	Fascia	1" x 8" x 10' SPF	2	\$6.65	\$13.30
	Fascia	1" x 8" x 12' SPF	2	\$7.98	\$15.96
	Soffit	1/4" x 4" x 8'	1	\$14.50	\$14.50
	Interior Sheathing	1/2" x 4" x 8' CDX	4	\$21.01	\$84.04
	Exterior Sheathing	1/2" x 4" x 8' CDX	2	\$21.01	\$42.02
	Insulation	R-19 Fiberglass Batt (100 SF)	2	\$14.99	\$29.98
	Felt	15# Asphalt Felt	1	\$13.94	\$13.94
	Shingles	Fiberglass	4	\$11.99	\$47.96
	Drip Edge	"D" Style 10' Lengths	5	\$2.78	\$13.90
HARDWARE	Slide Bolts for Doors	-	12	\$5.47	\$65.64
	Handles for Doors	-	8	\$6.24	\$49.92
	Weather-stripping	70 LF (10'/Package)	7	\$2.56	\$17.92
	Whole House Fans	-	4	\$37.99	\$151.96
	Dehumidifier	-	1	\$229.00	\$229.00
	Drain Hose	-	1	\$5.74	\$5.74
	Electric Space Heater	-	1	\$49.98	\$49.98
	Remote Hygrometer/Thermometer	-	1	\$54.68	\$54.68
MISC.	Exterior Stain	Gallons	2	\$20.96	\$41.92
	Paint for Interior	Gallons	2	\$15.98	\$31.96
	Anchor Seal End Coating	Quarts	2	\$18.00	\$36.00
TOTAL COST OF BUILDING MATERIALS					\$2,703.85

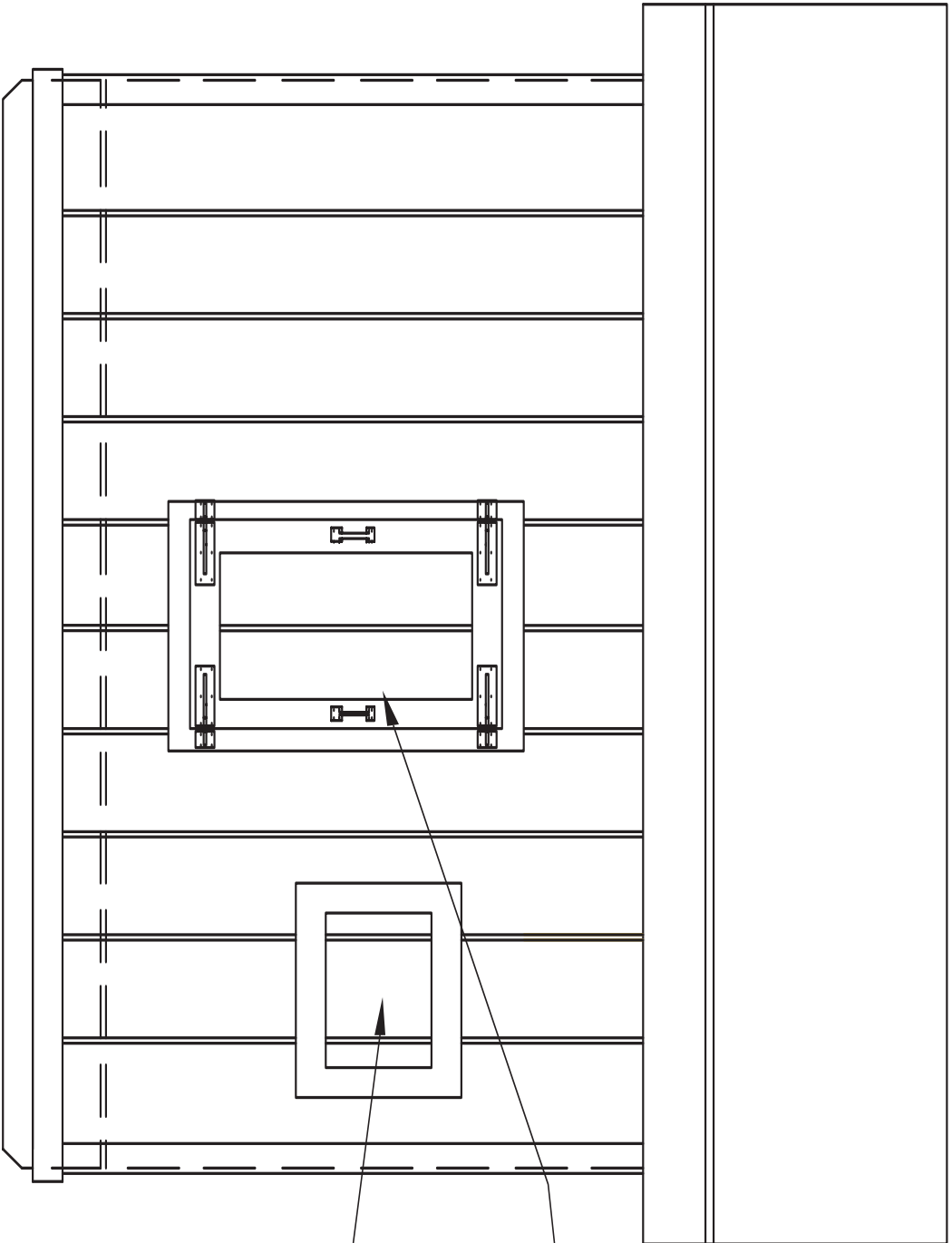
APPENDIX B-1: Plan View





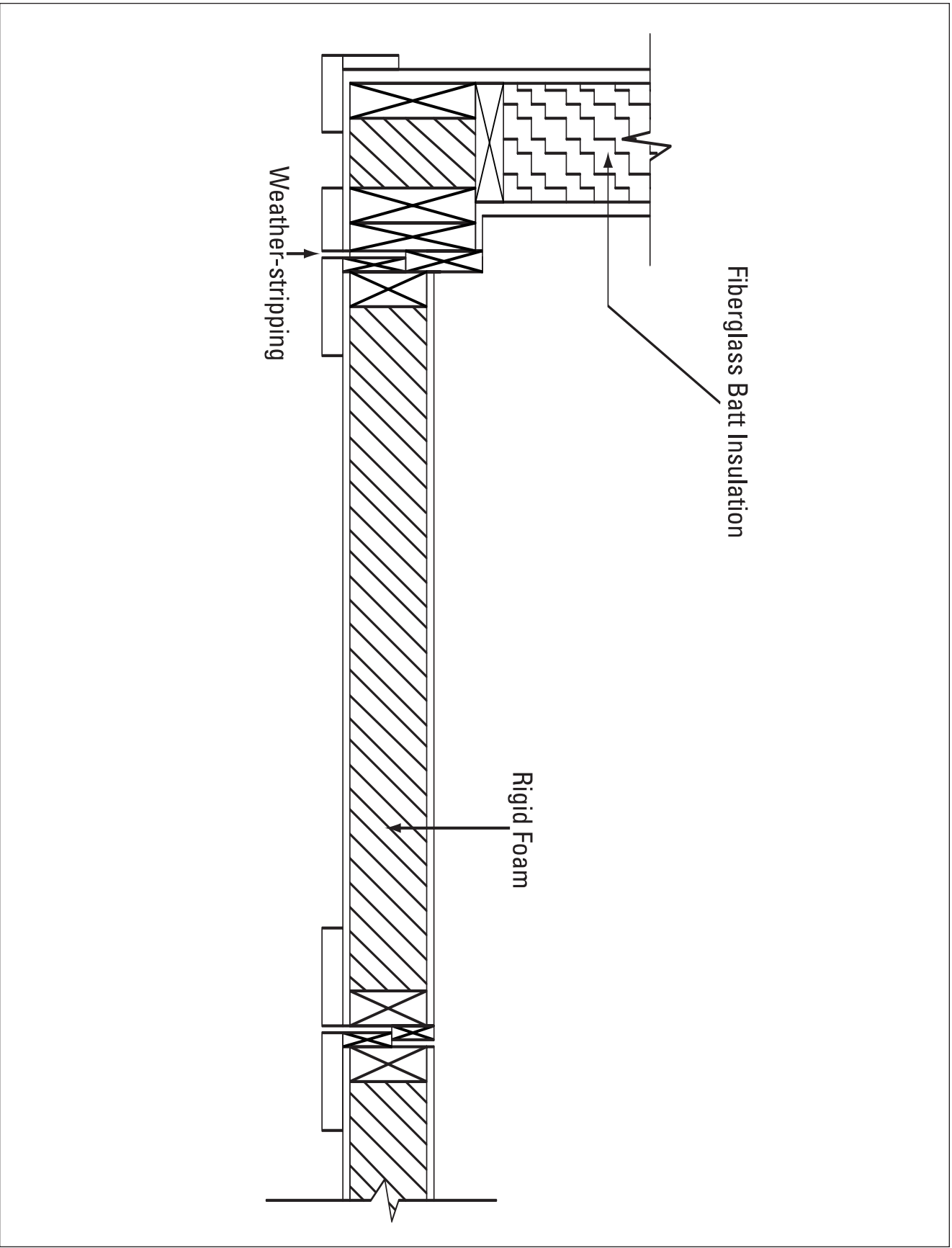
APPENDIX B-2: Section View

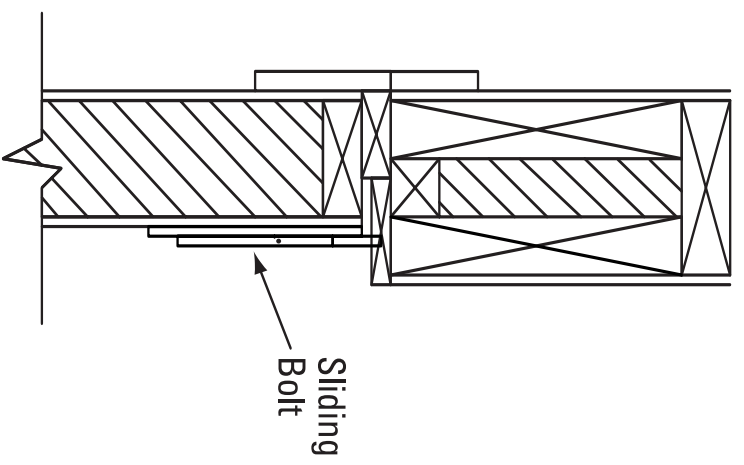




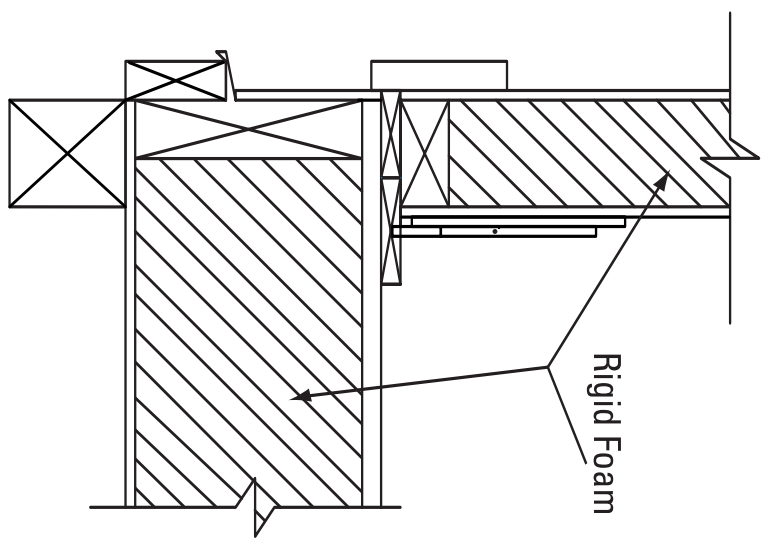
Access
Door for
Dehumidifier
Unit

Electrical
Panel





DOOR HEAD



DOOR SILL

PROCEDURES FOR CUTTING AND USING SAMPLE BOARDS

1. Select a few boards from the stack of lumber that represent the slowest drying material. These would be the widest, thickest, and highest moisture content boards. Boards that contain the most heartwood or are quartersawn are also suitable.

2. Cut a 24 to 30 inch sample that is free of knots and at least 12 inches from the end of the board. Then cut two one inch sections from the sample board as shown (see Figure A). Make sure to number the sections and sample board.

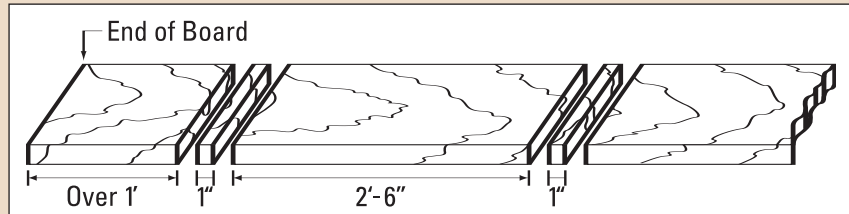


Figure A: Dimensions of a sample board for controlling the drying process.

3. Immediately weigh the one inch sections (accuracy of about one gram required) and record the weight. Measure immediately after cutting since it is important that they do not gain or lose weight before weighing.
4. End coat the sample board with a roofing cement or commercial end coating (see Figure B). Now, weigh the sample board and record the weight on the sample (accuracy of 0.1 pounds).
5. Place the sample board in the lumber stack in a location where it will dry at the same rate as the rest of the lumber in the dryer (see Figure C).
6. Place the one inch sections in an oven 215°F to 218°F (102°C to 103°C) and dry – usually 18 to 36 hours depending on the oven. Reweigh and obtain the oven dry weight.
7. Calculate the moisture content of each section and average the moisture content (MC) of two sections to obtain the moisture content of the sample board.

$$\%MC = \left[\frac{\text{Wet Weight}}{\text{Oven Dry Weight}} - 1 \right] \times 100$$

8. Estimate the oven dry weight of the sample board using average moisture content and weight from step #4, and record this so it can be used for future moisture content calculations.

$$\text{Estimated Oven Dry Weight} = \frac{\text{Wet Weight (Step \#4)}}{(100 + \%MC)} \times 100$$

9. To determine the moisture content at any time, reweigh the sample board and calculate.

$$\text{Current \%MC} = \left[\frac{\text{Current Weight}}{\text{Estimated Oven Dry Weight}} - 1 \right] \times 100$$



Figure B: Roofing cement and commercial end coating.

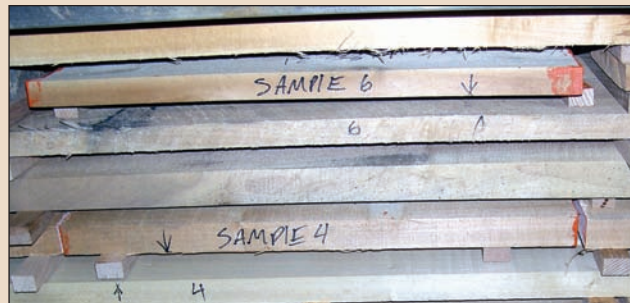


Figure C: Stack of lumber with sample boards.

6
↓
SAMPLE 4

↑
4

