DRY-KILN PROPOSAL FOR OKLAHOMA AGRICULTURAL AND MECHANICAL COLLEGE

DRY-KILN PROPOSAL FOR OKLAHOMA AGRICULTURAL AND MECHANICAL COLLEGE

By

LEROY H. BENGTSON

Bachelor of Science

Central State College

Edmond, Oklahoma

1936

Submitted to the Department of Industrial

Arts Education and Engineering Shopwork

Oklahoma Agricultural and Mechanical College

In Partial Fulfillment of the Requirements

for the Degree of

MASTER OF SCIENCE

1949

APPROVED BY:

Thesis Adviser and Head, School of
Industrial Arts Education
and Engineering Shopwork

Associate Professor, School of
Industrial Arts Education
and Engineering Shopwork

Dean, Oklahoma Institute of Technology

Dean, Graduate School

ACKNOWLEDGEMENTS

I express my gratitude for all the help I have received in this endeavor to those individuals who have given their time and suggestions.

For his assistance in the selection of a problem, for his encouragement and advice, I am deeply indebted to Dr. DeWitt Hunt, Head of the Department of Industrial Arts Education and Engineering Shopwork at Oklahoma Agricultural and Mechanical College. His careful, constructive criticism, and suggestions have been very helpful.

Much credit is due my wife, Mildred I. Bengtson, for the continued progress and completion of this study. Her sacrifices, assistance and encouragements were invaluable aids.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF RECORDS

CHAPTER I

INTERPRETATION OF THE PROBLEM

The problem of securing well seasoned lumber to be used in furniture construction at the Oklahoma Agricultural and Mechanical College has become more difficult in recent years. In some cases the lumber may have been in good condition when shipped from the supplier, but increases in moisture content in transit, because of damp weather, made it difficult to use. It is impossible to retain proper moisture percentages when lumber is exposed to high humidity conditions. This makes it important that the lumber be dried and stored properly at the place where it is to be used in furniture construction.

SELECTION OF THE PROBLEM

The plan to establish lumber drying facilities at Oklahoma A. & M. College has been considered for a number of years. The problem of securing good lumber became more apparent during and just after the war. The idea of constructing a modern dry-kiln and equipping it with modern equipment has been encouraged to make it possible to dry the lumber that is used in the school shops. A new course in Kiln Operation can be added to the curriculum of the Departments of Industrial Arts Education and Engineering Shop Work, and the Department of Forestry.

Origin of the Problem. The recent efforts to acquire this installation were begun when the writer of this report assumed the responsibility of managing the Oklahoma A. & M. College Cabinet Shop. At the request and with the support of Dr. DeWitt Hunt, who is the head of the department, this undertaking was begun. Correspondence with experts in the field of dry-kiln installation and operation was started. The response received made it more apparent that such an undertaking would be a sound investment and a profitable undertaking.

Feasibility of the Problem. After considering all of the aspects of this project, it seemed advisable to promote the idea. It was determined that native lumber is available for the operation of a small sized dry-kiln. This drying can be done on a toll basis, whereby the department can accept a part of the lumber as a fee for drying it. The faculty of the Department of Forestry at the college is a strong supporter in the proposal. Units of instruction can be prepared to expand the efficiency of each department. Research work can be done with the proposed facilities which would be a service to the producers of lumber in Oklahoma, as well as the consumers.

Dry-Kilns at Other Institutions. The first study of building plans was made of similar installations at other locations. The Texas Forest Service at Lufkin, Texas has a dry-kiln similar to the one in this proposal.

It is operated for experimental work and research. North Carolina State College at Raleigh, N. C. has a dry-kiln in connection with their Division of Forestry. It is very similar to the proposal at Oklahoma A. & M. College. The length is nineteen feet, the width, fourteen feet, and the height is eleven feet and six inches. It is equipped with three sixty inch fans. Other schools having dry-kilns are: (1) University of Florida, Gainesville, Florida; (2) Oregon State College, Corvallis, Oregon; (3) Clemson Agricultural College, Clemson, S. C.; (4) Alabama Polytechnic Institute, Auburn, Alabama; (5) Lee's McRae College, Banner Elk, North Carolina; and possibly others.

ANALYSES OF DRY-KILN INSTALLATION

It has been determined that dry-kiln installations at other colleges and universities have been successful. By having the management of the dry-kiln delegated to teachers in the Cabinet Shop, it will not be necessary to employ a full time operator for it. The necessary utility services are available at the proposed building site.

Attitude of the Department. This venture has the unified support of the Departments of Industrial Arts Education and Engineering Shop Work, and Forestry. Service courses for other departments can be provided. Special short courses can also be arranged for non-college people who are interested in the proper seasoning of lumber.

Attitude of the Administration. The College Administration is favorable toward the proposal. The College architect has been very cooperative in producing plans and estimates on the building. The Vice-President of the College is a firm supporter of the endeavor. He has recommended the project to the Business Manager and to the President with the added recommendation that funds be made available for the erection and equipping of the dry-kiln. Its constructions has been promised when the necessary capital is available.

Locations Considered. Several locations have been considered for the erection of the proposed dry-kiln. Other locations adjacent to the Industrial Arts Building have been considered as well as locations some distance away. After considering all details, it seems advisable to locate the building at the northeast corner of the southeast wing of the building. This location is easily accessible to the Cabinet Shop, and also to the driveway to the loading area. It is adjacent to the present lumber storage for the Cabinet Shop. This store-room has a capacity of at least one dry-kiln charge of lumber. The cost of construction can be reduced by using the present wall of the shop as one of the dry-kiln walls.

Building Plans Studied. Building plans, submitted by dry-kiln manufacturers, and those that are available from other institutions were examined, and the desirable features of each were recorded. A tentative plan was prepared by the College Architect, after making a study of these plans. This plan was presented to two major manufacturers of dry-kiln equipment, and was revised according to changes suggested by officials in these companies. The plans were then submitted to the technical staff of the U. S. Forest Products Laboratory for study. The recommendations of this department were used in making further modifications. From all of the study and research conducted, the present proposal has been accepted. Building plans produced by the U. S. Forest Products Laboratory were also examined. A number of dry-kilns that are in operation were visited to determine the efficiency of each.

<u>Request for Specifications</u>. Letters were sent to all of the manufacturers of dry-kiln equipment that are registered with the U. S. Forest Products Laboratory. This list included eighteen manufacturers and proposal specifications, and estimates were obtained from all except one of these firms. One firm located in Washington sent the reply that it would be inadvisable for it to make an estimate on the installation because of the distance involved. It would be too expensive to ship equipment such a great distance, and the expense of the supervising engineer would be too great.

<u>Study of Equipment</u>. An extensive study has been made of all the available types of dry-kiln equipment submitted by several manufacturers. The principles of drying lumber in a compartment type dry-kiln are well established

and the problem of selecting equipment that is the most efficient, and sells at a reasonable price have been the governing factors in the final decision. It seems advisable to install the most modern equipment operated from an automatic control system. A number of dry-kiln units that are used by the U. S. Forest Products Laboratory were examined by the writer in an effort to make the proper recommendations for this proposal.

Delimitations. The most of the reliable information about dry-kiln construction and operation that is available has been prepared by the U. S. Forest Products Laboratory. The manufacturers of dry-kiln equipment cooperate with this laboratory in developing efficient equipment and methods for drying lumber. There has been a great amount of technical material prepared and published by the U. S. Forest Products Laboratory, and it is available to the public without cost. Other printed materials about kiln drying are available from the United States Government Printing Office at a small cost.

The writer has found it necessary to confine the material in this report to the essentials to use as a guide for the construction and operation of the proposed dry-kiln for the Oklahoma A. & M. College. The above mentioned essentials were considered in the study made by the writer while at the U. S. Forest Products Laboratory.

Educational Values. This subject will be beneficial to the educational curriculum only as a specialized technical subject to be taught to a few individuals who expect to become dry-kiln engineers. Also, there will be general educational value to students of Industrial Arts Education, and Trade and Technical courses. Research work can be done in the field of kiln drying of wood. Students of Industrial Arts Education will be better able to understand the process of dry-kiln operation by actually handling the material and equipment involved.

DEFINITIONS OF TERMS AND FORMULAS STATED

This section is included for the purpose of defining some of the technical terms that are used in this report. In most cases, these terms are not explained where they appear in the report.

Absolute Humidity, the actual amount of water vapor, by weight, which a cubic foot of air contains.

Anemometer, an instrument used to measure the velocity of air.

Bound Water, water which is soaked up in the cell walls.

Capillary Forces, those forces which tend to keep water in wood.

Case-hardening, a condition resulting in a piece of uniformly dried lumber in which the interior fibers are in tension, and the outer fibers are in compression.

Cavities, cells and pores.

Cell, a term applied in a general sense to the minute units of wood structure.

Collapse, an abnormal shrinkage which results in crushing of the cells.

Compression Wood, abnormal wood formed on the lower side of branches and leaning trunks of softwood trees.

Conifer, a tree bearing seed cones; usually an evergreen.

Constantan, an alloy of equal parts of nickel and copper, used in some electric resistance standards.

Crooking, a deviation edgewise from a straight line drawn from end to end of a piece of lumber.

Dry-bulb, measures air temperature.

Dry-kiln, is composed of one or more chambers, rooms, or tunnels in which temperatures and relative humidities can be maintained at any desired level by means of either manual or automatic control.

Equilibrium Moisture Content, the moisture content at which wood neither gains nor loses water when surrounded by air at a given relative humidity and temperature.

Established Moisture Content, average moisture content at the time of use.

Fiber Saturation Point, the moisture content at which the cell wall is saturated with water, but no water exists in the cell cavity; usually about 30% based on the oven-dry weight.

Free Water, held in cell cavities.

Graph, a pictorial representation of some data.

Green Weight, weight of wood plus the weight of water it contains.

Gymnosperms, fruit or cone of a softwood tree.

Heartwood, consists of tissue which is no longer active in promoting the rise of sap in the tree and performs only mechanical function of insuring strength to the tree stem.

Honeycombing, internal checking, which usually develops along the wood rays.

Humidity, the amount of moisture in the air.

Hygroscopic, ability to hold moisture and give up moisture.

Hygrostat, an instrument which shows variations in atmospheric moisture.

Medullary Rays, parallel lines or bands which extend across the grain of the wood.

Moisture Content, calculated by dividing the weight of water removed by the oven-dry weight of the section and multiplying the quotient by 100.

Oven-dry Weight, weight after all moisture is removed.

Pit, a relatively unthickened portion of a cell wall where a thin membrane permits liquids to pass from one cell to another.

Pit-membrane Openings, permit movement of material from one cell to another.

Potentiometer, an electrical network used for the measurement of voltage, in which the fall of potential (voltage) over a known part of a conductor is balanced against the voltage to be measured.

Rays, strips of cells extending radially within a tree. The rays serve primarily to store food and transport it horizontally in the tree. The rays run in a radial direction and add strength to the wood.

Recorder-controller, a combined thermostat and recorder in which the temperature-sensitive element regulates the air supply to the diaphragm-motor valve and also moves the recording-pen arm.

Relative Humidity, the amount of moisture in the air at any given temperature as compared to the quantity it is capable of holding if saturated at the same temperature.

Sapwood, encircles the heartwood and is lighter in color and generally lighter in weight when oven-dried.

Stain, a chemical discoloration of wood apparently due to oxidation and accumulation of extractives under certain conditions during the air drying or kiln drying of various species.

Stickers, strips used for the purpose of separating the boards, providing space for drying air currents and assisting in keeping the lumber straight and flat during the drying process.

Temperature, the degree of hotness or coldness of a substance, measuring the intensity.

Thermocouple, consists of a pair of dissimilar metals joined together at one end. The difference in electromotive force (microvolts) between this junction and the junction in the potentiometer is measured by the balancing mechanism of the potentiometer, and the result is read in degrees of temperature.

Thermostat, an instrument used to control temperature.

Transitory Cell Wall Passageways, exist within the cell wall only when a liquid separates the submicroscopic components of the wall and disappear when the liquid is removed.

Veneer, thin sheets of wood cut in one of three ways: sawing, slicing, or rotary cut.

Warp, any variation from the true or plane surface. Warp includes crook, bow, cup, and twist, or any combination of these defects.

Wet-bulb, measures the amount of moisture in the air.

Wet-bulb Depression, the difference between the wet-bulb temperature and dry-bulb temperature.

Formulas Used for Calculations. It is necessary for the dry-kiln operator to understand and be able to use the following formulas in order to control the processes involved in the drying and conditioning of lumber. These formulas are obtained from bulletins that were prepared by the U. S. Forest Products Laboratory. Letter abbreviations will be used to make these formulas shorter and will be listed below.

M. C. % . . . . Moisture content in percent.

C. O. D. W. . . . . Calculated oven-dry weight.

C. M. C. . . . . Current moisture content.

R. H. % . . . . Relative humidity in percent.

Shrinkage % . . . . Shrinkage in percent.

Y . . . . .Parabolic curve.

Avg. M. C. . . . . .Average moisture content.

$$\text{M. C. \%} = \frac{\text{Original Wt. - Oven-dry Wt.}}{\text{Oven-dry Wt.}} \times 100$$

$$\text{C.O.D.W.} = \frac{\text{Green Wt. (or current wt.)}}{\text{M.C. in \%} + 100} \times 100$$

$$\text{C. M. C.} = \frac{\text{Current Wt. - C.O.D.W.}}{\text{C.O.D.W.}} \times 100$$

$$\text{R. H. \%} = \frac{\text{Partial Pressure}}{\text{Saturated Pressure}} \times 100$$

$$\text{Shrinkage \%} = \frac{\text{Green Dimension - Dry Dimension}}{\text{Green Dimension}} \times 100$$

$$Y = 3/2\ (\text{average M. C. - E. M. C.}) + \text{E.M.C.}$$

(Y E. M. C. of Midthickness)

$$\text{Avg. M. C.} = \frac{2Y + \text{E. M. C.}}{3}$$

CHAPTER II

THE MOVEMENT OF MOISTURE IN WOOD

The dry-kiln operator must have some knowledge of the structure of wood and what takes place when it dries in order to control kiln conditions. The physical features of various species of wood differ. The kiln conditions must be adjusted and maintained for the particular specie being dried. A definite schedule must be followed to produce desired results.

STRUCTURE OF WOOD AS IT IS RELATED TO SEASONING

Wood is a complex natural material that is built up by a living plant. A tree grows by producing cells from living tissues. These cells are deposited in layers around the previous season's growth. These new layers of growth are known as annual rings. The texture of the tree changes as these rings continue to form. The outer layers are sap-wood and the inner part is heart-wood. The heart-wood composes all except about eight years growth of the tree. Wood is classed as soft-wood and hard-wood. Soft-wood comes from trees that are called coniferous whose fruit is a cone (gymnosperm). Hard-wood belongs to the group of angio-sperms.

Moisture Passageways. Moisture moves in wood through several distinct kinds of passageways, which constitute the capillary structure. Some of these passageways in certain kinds of woods are large enough to be visible to the naked eye, some may be seen only through strong microscopes, and others are present only when the cell walls are swollen by water or some other swelling agent.

Bound-water and Free-water. Wood contains bound-water and free-water. Bound-water moves in the cells and between the cells by diffusion, while capillary action causes the free-water to escape through cell cavities, pit chambers, and pit-membrane openings. The drying by diffusion takes place only after the free-water has been removed by capillary action. Two types of diffusion take place in drying; more through the transitory cell-wall passageways at low temperature, and larger passageways at higher temperatures. Diffusion is slower in heartwood than in sapwood because of obstruction in the pit-membranes in the heartwood.

Directions of Moisture Movement. Moisture passage takes place both longitudinally and laterally through cavities, pit chambers, pit-membrane openings of wood cells, and the transitory cell wall passageways. These moisture passageways may constitute from twenty-five percent to eighty-five percent of the total volume of the wood. The woods having the higher percentages have the lower specific gravity. The water passage is fifteen times greater longitudinally than laterally.

Cavities. The cavities of fibers and vessels, are at times visible to the nakes eye (as are the large pores of some hard-woods) and at other times are so small that a miscroscope is required to see them. These cavities are filled with free-water and air. The free-water moves from cell to cell until the fiber-saturation point is reached, at which time the remaining free-water is absorbed by the cell walls.

Wood-ray Cells. Wood-ray cells may be seen only with a microscope. Large wood-rays consisting of many cells are often visible to the naked eye. Wood rays extend in a radial direction across the wood, and are usually found in vertical sheets.

Pit Chambers. Pit chambers and their pit-membrane openings permit the movement of a material from one cell to another. Pit chambers are visible only under a microscope, and pit-membrane openings are often invisible under the highest-powered microscope. Free-water and also vapor move through these openings.

Resin Ducts. Resin ducts are sometimes visible to the naked eye, but the intercellular spaces are visible only under a microscope. These ducts retard the movement of water through the fibers. As the heart-wood becomes dormant, the spaces are filled with a deposit of resin.

Transitory Cell-wall Passageways. These passages exist within the cell-wall only when a liquid separates the sub-microscopic components of the wall, and disappear when the liquid is removed. These passageways are invisible under an ordinary microscope.

Since the bound-water in a piece of lumber must pass through the cell walls from the cell cavities as a vapor, the process is rather slow. It is impossible to force the water too rapidly from the cells of the wood without damage to them. Forced drying conditions must be kept balanced and uniform throughout the drying period. A moisture regain can be expected in the same manner when dry lumber is placed in damp conditions.

METHODS OF DETERMINING MOISTURE CONTENTS

The moisture content of a piece of lumber will limit its use to a certain extent. Some types of construction require a low moisture content while others do not. The purpose of the dry-kiln is to reduce the moisture content below the point that it will naturally assume, or to reduce it from a high percentage to some lower percentage in a short time. Two general methods are used to determine the amount of moisture contained in a piece of lumber; namely, the oven-drying, and the electro-moisture meter.

Oven-drying. Oven-drying is the standard and most reliable method used in determining the moisture content in wood to be used in the construction of wood products. The moisture content is calculated from weight values obtained before and after drying a sample of the wood in an oven. This method consists of selecting representative sample boards or pieces from the material to be tested, cutting moisture sections from each sample, weighing them, drying them in an oven to constant weight, weighing them again, and calculating the moisture content. It is important that these samples are representative and of sufficient numbers taken at different places in the kiln load to insure an accurate test of conditions of the load.

These sample or moisture sections should be taken from a board at a distance of at least twenty inches from the end of the board because the drying is more rapid at the ends of the board. Sections should be approximately one inch thick for one-inch lumber and two inches in length for dimension stock where the cross-sectional dimensions are one inch or less. All samples should be cut on a cool running bandsaw and loose splinters and sawdust should be removed. The weight of the sample whould be taken immediately to get the weight before evaporation takes place from the end grain. When a number of samples must be cut before weighing, each sample should be wrapped in aluminum foil or samples should be stacked with the end grain of the sections together to prevent evaporation. All weights should be made in grams with a triple-beam balance so that calculations will be simplified by the decimal system. The weight should be marked on each section and recorded on a tabulation sheet.

Sections should be placed in an oven at a temperature of 212° to 221° fahrenheit (100° to 105° centigrade) and dried until a constant weight is reached. Low-density woods will usually dry in twelve hours, and high-density woods in about forty-eight hours. The weight of each sample should be taken and recorded as soon as it is removed from the oven to prevent an error which could occur from a moisture regain. (Use the minimum weight of the samples recorded, and take this reading as a basis for determining schedule for drying.)

The moisture content of the wood is calculated by dividing the weight of the water removed by the oven-dry weight of the section and multiplying the quotient by 100. The weight of the water equals the original weight minus the oven-dry weight of the section.

$$\underset{\text{(Per Cent)}}{\text{Moisture content}} = \frac{\text{Original weight - Oven-dry Weight}}{\text{Oven-dry weight}} \times 100$$

An example of moisture content calculation is as follows: A one-inch section of kiln-dried black walnut lumber weighed 56.5 grams. After oven-drying, the section weighed 52.5 grams.

$$\text{Moisture content} = \frac{56.5 - 52.5}{52.5} \times 100$$

$$= \frac{4.0}{52.5} \times 100$$

$$= 0.076 \times 100$$

$$= 7.6 \text{ percent}$$

When slide-rule calculations are desired, the following formula may be used:

$$\text{Moisture content (Per Cent)} = \frac{\text{Original weight}}{\text{Oven-dry weight}} - 1 \times 100$$

$$\text{Moisture content} = \frac{56.5}{52.5} - 1 \times 100$$

$$= (1.076 - 1) \times 100$$

$$= 0.076 \times 100$$

$$= 7.6 \text{ percent}$$

7.6 percent equals the percentage of water remaining in the wood, as compared to the weight of the kiln dried sample.

Electro-moisture Meter. The electro-moisture meter method of determining moisture content is the most rapid, but is not as accurate and reliable as the oven-dry method. The resistance-type meter is reasonably accurate in measuring moisture contents of wood containing from seven percent to twenty-five percent. The wood acts as a rssistance element in the electrical circuit of the moisture meter. Needles are placed one-half inch apart on the retaining bar and one and one-fourth inches between the pairs. These points should be about five-sixteenths inch in length and placed in the wood so that the current will flow parallel to the grain. The current will flow between the points where there is the greatest amount of moisture because there is less resistance. These instruments are calibrated to give the moisture content of veneers by placing one contact point on each side of the veneer, thus measuring the resistance through the layer of wood.

Another type meter is used which indicates the relation between the moisture content and dielectric constant and is known as the capacity of radio-frequency power-loss type. The radio-frequency current is established in a vacuum-tube circuit and applied to a condenser which is pressed against the surface of a board. The dielectric properties of the wood cause a reaction which is indicated by a current meter.

The accuracy of moisture-meter determinations are affected by: (1) species, (2) specific gravity, (3) moisture distribution, (4) thickness of material, (5) temperature, (6) contact, (7) grain direction, (8) high relative humidities, (9) number of measurements, and (10) the personal elements.

The moisture meter should not be used as an instrument to control the kiln-drying schedule because inaccuracies may occur. It may be used in segregating lumber into moisture content ranges before kiln drying or for finding the average moisture content of a charge as it is taken from a kiln, provided enough samples are used to make the test reasonably reliable. Most modern moisture meters will check to an accuracy of plus or minus one percent. Each instrument will be supplied with instructions and charts for corrections or applications to be used in testing the lumber. Most moisture meters are calibrated to read for Douglas fir, but are supplied with correction tables to be used for other species of wood.

SHRINKAGE OF WOOD

Shrinkage in the drying of wood is proportional to the amount of moisture lost below the fiber-saturation point. There is no swelling or shrinking of wood as it takes up or gives off water above the fiber-saturation point. This point is about thirty percent in most woods. As a piece of green lumber dries it starts from the outside and soon has a much lower percentage of moisture near the surface than toward the inside. In this case shrinkage will start near the outside while the inside still remains above the fiber-saturation point. The method of drying a board may have a marked effect upon the amount of shrinkage produced during the process.

> In drying wood to a moisture content of fifteen percent, one-half of the total shrinkage takes place; while in drying it to a moisture content of six percent, four-fifths of the total shrinkage takes place.[1]

Lumber that is to be used for outside construction or framing should be dried to about fifteen percent moisture content. Since this is about the average percentage that will be maintained through normal weather conditions, a small amount of additional shrinkage or expansion will take place. When lumber is dried to six percent, additional

---

1. Shrinkage of Wood, U. S. Forest Products Laboratory, Bulletin No. R1650, page 2.

shrinkage will not take place due to atmospheric conditions, but expansion will result with the increase of moisture content. These factors must be taken into consideration when projects are made especially those having moving parts, such as drawers.

Tangential Shrinkage. The greatest amount of shrinkage is in the direction of the annual growth rings (tangentially). This type of shrinkage is of most importance because most of the lumber is flat-sawed. Tangential shrinkage is in most cases about twice as great as radial shrinkage.

TABLE I

Percentage of Shrinkage Due to Drying
(Given in percentage of green size)[2]

Direction of Shrinkage	From green to oven-dry condition	From green to air-dry condition (12 to 15 percent moisture content)
	Percent of green size	Percent of green size
Tangential	4.3 to 14.0	2.1 to 7.0
Radial	2.0 to 8.5	1.0 to 4.2
Longitudinal.	.1 to .2	.05 to .1
Volumetric.	7.0 to 21.0	3.5 to 10.5

Radial Shrinkage. Radial shrinkage is radially with the grain of the wood. This type of shrinkage is about one-half to two-thirds as much as along the grain. Less shrinkage takes place in quarter-sawed than flat-sawed lumber.

2. Shrinkage of Wood, U. S. Forest Products Laboratory, Bulletin No. 1363, page 1.

Wood-ray cells shrink chiefly along their length.

Longitudinal Shrinkage. The longitudinal shrinkage, that is with the grain, amounts to only one-tenth to two-tenths of one percent of the length of the board. Greater longitudinal shrinkage occurs when the board is cross-grained, in which case, it is a combination of crosswise and longitudinal shrinkage.

Volumetric Shrinkage. The volume of a board decreases up to twenty-one percent when changing from green to oven-dry conditions. This is a combination of the above factors.

TABLE II

Relative Weights and Shrinkage of Common Woods.[3]

Name of wood and locality grown	Wt. per cu. ft.-lbs.			Percentage of shrinkage from green to oven-dry wt.	
	Kiln dry	Air dry	Green	Radial	Tangen.
Ash - Tennesse	27	28	46	4.2	6.9
Basswood - Wisconsin	24	25	41	6.2	8.4
Birch - Pennsylvania	45	47	59	6.9	8.9
Elm, White - Wisconsin	35	35	53	4.2	9.5
Gum - California	--	36	46	7.6	15.3
Maple - Wisconsin	42	44	56	3.0	7.0
Oak, White - Arkansas.	46	48	59	6.2	8.3
Walnut, Black - Kentucky. . . .	41	44	58	5.2	7.1
Cedar - Montana.	21	22	24	2.5	4.6
Cypress - Louisiana.	33	34	51	3.8	6.0
Pine, White - Wisconsin. . . .	26	27	39	2.2	5.9
Pine, Longleaf - Mississippi	38	40	42	4.8	7.5
Redwood - California	23	24	38	---	---

RELATIVE SHRINKAGE AND WEIGHTS OF COMMON WOODS

Drying decreases the weight of the green wood because

3. A Manual for Hand Woodworking, DeWitt Hunt, page 62.

twenty-five to forty percent of its weight is water. Table II shows the relative weights and shrinkage of some of the woods in common use.

It is possible to select the proper wood for construction work when the requirements are known and the amount of shrinkage that can be expected in the different kinds of lumber. The weight of wood is seldom considered when making a selection of lumber for common construction work, but must be considered when used in air craft, boat, and other similar construction.

> In general, the heavier species of wood shrink more across the grain than the lighter ones. Heavier pieces also shrink more than lighter pieces of the same species. When shrinkage is more of a factor than hardness or strength a lightweight species should be chosen. When both hardness or strength and low shrinkage are very important, then the exceptional species, such as black locust, should be chosen.[4]

A study should be made of dimensional changes of wood when shrinkage, hardness, and strength are important factors in construction work or other uses of wood. A knowledge of dimensional changes in wood should be considered in all construction.

WARPAGE IN WOOD

Warpage in wood is caused by uneven shrinkage and improper lumber piling. Warpage may result in any one or more of the following; cupping, bowing, crooking, twisting,

---

4. Bulletin No. 1363, op. cit., page 2.

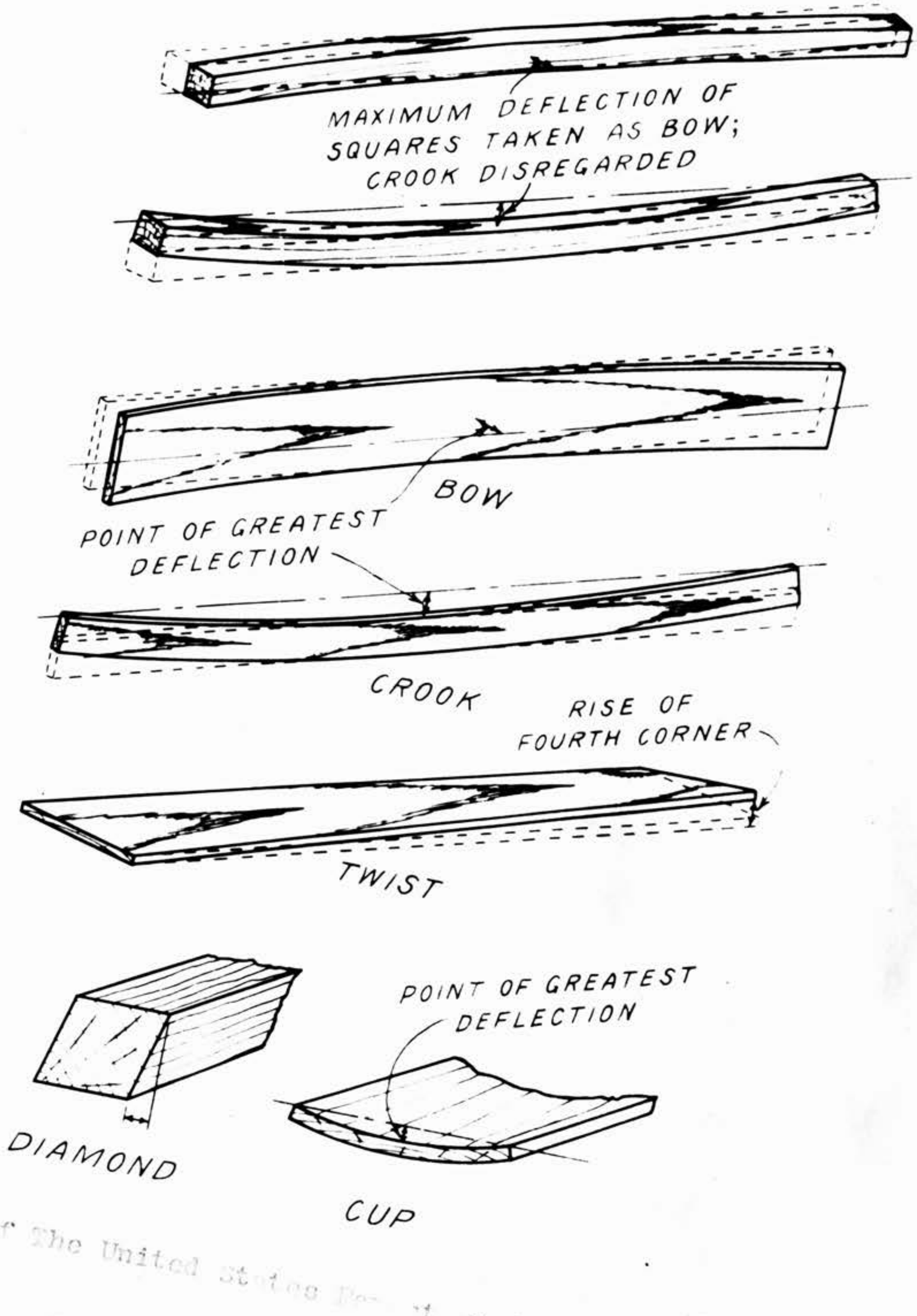
or diamonding. Any of these conditions will produce inferior lumber. Cupping may result from greater shrinkage of the outer face of a plain-sawed board or from uneven drying of the two faces of a board. The other types of warpage are caused by irregularities of the structure of the wood; such as, spiral, grain, and compression wood. Figure I shows these kinds of warpage.

Damage Caused by Warping. Much valuable lumber is lost because the desired thickness cannot be obtained due to warpage. Irregular longitudinal shrinkage causes bowing and crooking of a piece of lumber. Compression wood may cause an abnormal amount of longitudinal shrinkage.

Minimizing Warpage. Warpage can be minimized to a great extent by proper stacking and drying. It should be stacked in an orderly manner as soon as it is sawed. This will be discussed fully in Chapter VII. Proper drying conditions will reduce the amount of poor lumber caused from warpage. Much cupping can be avoided when proper air circulation is provided on both faces of the lumber in the dry-kiln. Moderate drying conditions in the kiln will also produce less warpage than severe conditions. Lumber that is properly handled in the kiln or in air-drying will give much better results than poorly handled lumber. Much lumber loss can be avoided by using approved sawing methods.

LUMBER STRESS

Uneven stresses set up in lumber by improper drying



Courtesy of The United States Forest Products Laboratory

[illegible] LUMBER

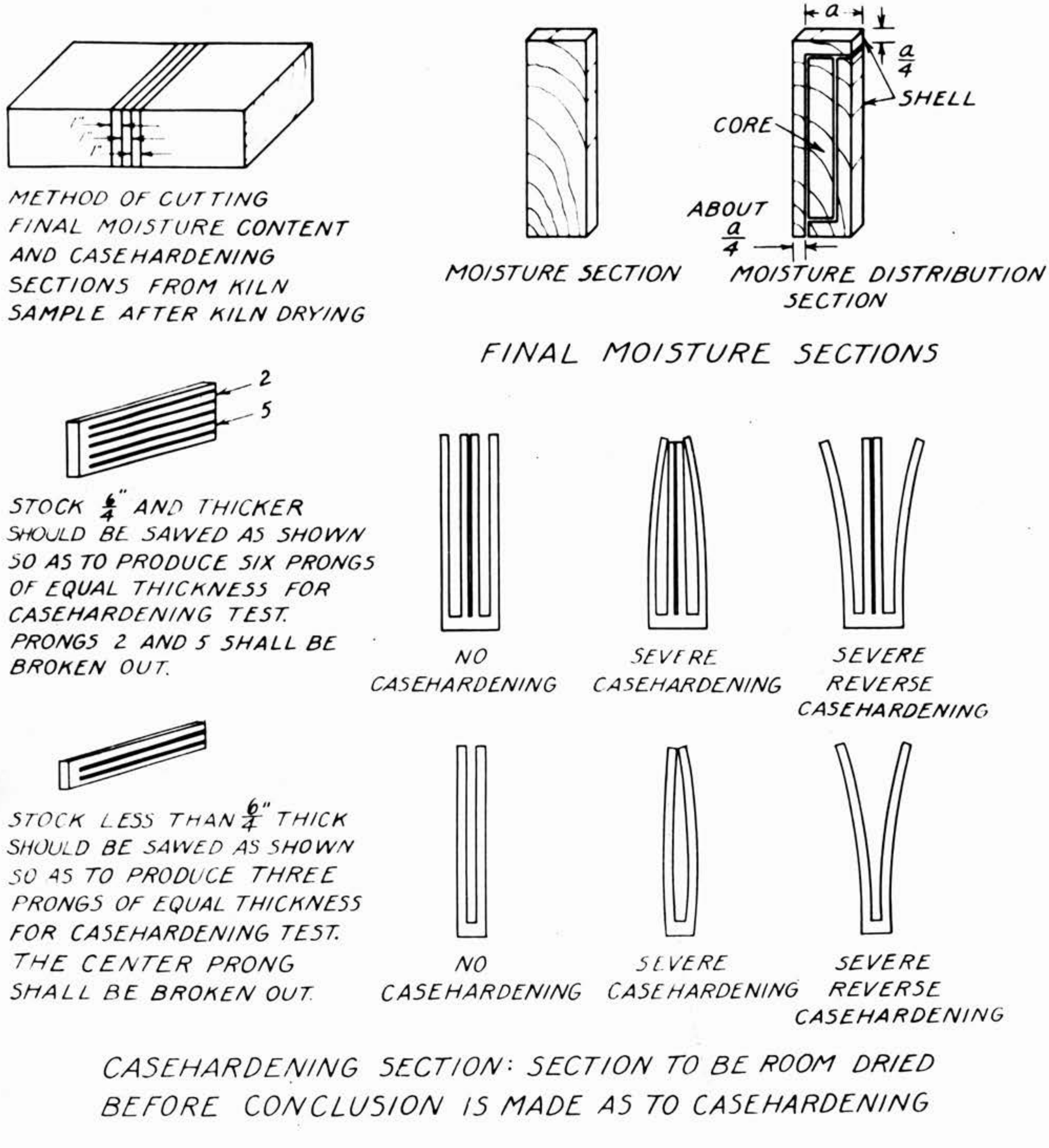
Figure 1.

and conditioning will result in warpage. The proper time to measure and relieve stresses is while the lumber is still in the kiln. The relief of stress will be discussed in the conditioning treatment in the operation of the kiln in Chapter VII.

Effect of Stress. Stress will cause a distortion of lumber while it is being processed. When more material is removed from one face of a board than the other a great amount of cupping may result. Lumber in stress will produce cupped boards when resawed. These conditions will result in many rejects due to thin material when processed. Some stress may occur in properly dried and conditioned lumber due to humidity conditions where it is stored or used.

Testing for Stress. Stress sections may be taken from samples in the dry-kiln to determine the amount of moisture in the shell of the board and the core. When there is a great amount of difference in the moisture content, stress is bound to occur. Figure 2 illustrates the method of making stress sections. The section showing the final moisture distribution is made to test the moisture content of the core and the shell by oven-drying and calculating the percentage of moisture of each.

Casehardening. Casehardening is a condition resulting in a piece of uniformly dried lumber in which the interior fibers are in tension and the outer fibers are in



Courtesy of The United States Forest Products Laboratory

Figure 2.

compression. Casehardening is evidenced by the appearance of surface checking and excessive warping and twisting during the drying process. This condition may result from air drying or kiln drying of lumber.

> In early stages of its development the shell is shrinking accompanied by surface stresses. If these become severe enough, the wood fractures and surface checks appear. The more rapid the surface drying is compared with the core the more likelihood of creating severe casehardening and surface checking. Hard refractory woods caseharden and check more severly than the soft textured ones.[5]

A test may be made for casehardening by the method indicated in Figure 2 of this chapter. If lumber is casehardened, the outer prongs of the sample will turn in when the center one is removed. Casehardening may be minimized by proper drying and humidifying. When casehardening does appear in a dry-kiln, it may be relieved by the proper conditioning treatment which will be discussed fully in Chapter VII.

Reverse Casehardening. Reverse casehardening occurs when the conditions of a piece of lumber are the opposite of casehardening. If too much water is absorbed during the conditioning treatment to relieve casehardening the outer surfaces will swell enough to take on an excessive compression set. The inner fibers will then be in tension, and when a sample is prepared the outer prongs will turn out in-

---

5. Air Seasoning and Kiln Drying of Wood, H. L. Henderson, page 117.

stead of in as in casehardening. Reverse casehardening is more difficult to remove than casehardening and the process is long and expensive.

Splitting and Checking of Wood. End splitting, end checking, and surface checking develop in lumber when the moisture content of the surfaces on which they occur is reduced so low as to cause stresses that exceed the maximum tensile strength of the wood perpendicular to the grain. These stresses are caused when the outer surfaces expel moisture at a more rapid rate than the interior sections. They tend to shrink and the inner sections do not because of a higher moisture content. Surface checks may close after the center part of the lumber shrinks, but the weakness caused by these checks still exists. End checks and splits always produce low grade lumber.

Collapse. Collapse is the result of abnormal shrinkage which results in the crushing of cell walls. Collapse may occur when the outer surfaces of a piece of lumber are in tension and the inner part is in compression. This is usually caused by excessive heat. Collapse may also occur when the cell cavities of the wood are completely filled with water and evaporation takes place more rapidly than the water is removed from the cell walls. The cohesive action of the water upon the cell walls causes them to draw together and results in collapse. This can take place only in cases where no air is present, and usually occurs in the early stages of drying green lumber.

Honeycombing. Honeycombing is the result of stresses causing internal checking along the wood rays. This condition may exist in casehardened lumber where the exterior surfaces are set in tension, and the interior shrinks due to excessive temperatures. A 100 percent relative humidity conditioning treatment for casehardened lumber may cause internal tension stresses that exceed the maximum tensile strength of the wood perpendicular to the grain and cause honeycombing. This defect is not usually visible from the surface, but is encountered when it is surfaced.

The skilled kiln engineer can reduce lumber rejects by making a study of the conditions of the lumber to be dried, and then selecting the proper drying schedule. If lumber is damaged in air-drying, the kiln engineer can do nothing to improve the quality except reduce the moisture content.

CHAPTER III

TYPES OF LUMBER DRY-KILNS

Dry-kilns may be of a number of types or general classifications. They may be grouped according to the principles involved in their function, or by types of drying equipment used. The efficiency required of the unit will depend upon the exactness desired in the finished product. Some kilns are used to speed up the time of drying lumber from the green stage to a normal moisture content that could be expected in air-drying over a longer period of time. Others are used to bring the moisture content to about seven percent for lumber that is to be used in furniture construction.

GENERAL CHARACTERISTICS OF DRY-KILNS

Dry-kilns are of two general classes; namely, progressive and compartment. These two types may be classified according to air circulation and heat transfer as follows: natural-air-circulation, forced-air-circulation, and heat-conduction kilns.

Materials. The most satisfactory material for the construction of a good dry-kiln is dense hollow tile. However, they may be built of lumber, brick, concrete, or other similar building materials. This phase of dry-kiln construction is discussed fully in Chapter IV.

Size of Kiln. Kilns may vary in size from one which accomodates a charge of not more than one hundred board feet of lumber to one which will hold as much as 200,000 board feet of lumber. The width for a single truck of end piled lumber is usually about twelve feet with an added space of ten feet for each additional truck. Where cross-piling is practical, the width will vary from eighteen to twenty-two feet with an added width of eighteen feet for each extra truck. The length of a kiln may vary from twenty feet for a single truck to two hundred or more feet for extra trucks. The height of the kiln will depend upon the height of the charge and the amount of space that is required for the machinery used for drying. Where fans are located below the charge, it may be necessary to elevate the tracks and fans above ground level if the locality is such that seepage may cause trouble. This will present the problem of having the loading and unloading tracks above the floor level. Where overhead fans and coils are used, the tracks may be placed on the ground level, which enables the operators to move the trucks more easily.

Heating. Steam coils or unit heaters usually supply the heat for a kiln, although some are heated by smoke pipes or house radiators. Natural circulation kilns must have the supply of heat below the track level while in those using forced-circulation, internal fan types of equipment may have heat supplied from the top or the under side of the load. Blower type kilns are usually heated by unit type heaters located on either the high-pressure or low-pressure side of the charge.

Humidity. Humidity conditions must be controlled at all times in a kiln to insure proper drying. There is usually sufficient moisture evaporated from the lumber in the early stages of drying to insure the proper relative humidity, but in the last stages of drying and conditioning, it may be necessary to add moisture from a steam spray or water spray system. All kilns are equipped with some type of ventilators to help in controlling relative humidity conditions. These ventilators may be operated automatically or manually to remove excess moisture when necessary.

Circulation. Load and fan baffles are required in a forced circulation kiln, to prevent short-circuiting of the air away from, and to deflect it to the lumber. These baffles should extend from the top of the load to the ceiling, and from each end of the load to the end of the kiln.

HOW A KILN FUNCTIONS

The function of the dry-kiln is to remove a certain amount of moisture from the lumber without causing damage to the wood structure. Lumber loss from degrades caused from checking and warpage can be minimized in a dry-kiln where drying conditions can be controlled and regulated. Sterilization treatments can be given to retard or stop the growth of mold and stain.

> Lumber is kiln dried by circulating air, controlled with respect to its temperature and humidity, through the kiln charge to evaporate the water contained in the wood and expel it from the kiln.[1]

Air must be circulated in a kiln to transfer the heat from the heating coils so that the moisture in the lumber can be evaporated and carried away. If the circulation of the air is not uniform and adequate throughout the kiln, poor results will be obtained due to cool spots in the charge. The more rapid the moisture diffuses throughout the wood, the more rapid the circulation of the air should be. The moist hot air will be expelled through the vents and will be replaced by fresh dry air drawn from the outside and through the heating coils. If the moisture is not removed from the kiln, the relative humidity will increase until drying of the lumber will stop.

Natural Circulation. In natural-circulation kilns, the movement of the air is much slower than in the forced-circulation type kilns and drying will be slower. The more rapid the circulation of the air, the more efficient the drying system will be. The rapid movement of the air will take up heat from the coils to be distributed through the kiln. Heat is usually furnished by steam coils, although it may, in some cases, be furnished from open fires or smoke flues.

---

1. Types of Lumber Dry Kilns, U. S. Forest Products Laboratory, Bulletin No. R1661, page 3.

It is important that the relative humidity be controlled in addition to applying heat to insure proper drying conditions. Where heat alone is applied, the lumber will dry too rapidly on the outside and damage will occur. The circulation of the air must be uniform throughout the kiln.

> Improper radiation, humidification, air circulation, ventilation, piling and loading practices, and kiln and equipment maintenance, individually or collectively, will produce unsatisfactory drying results. Even if all these factors are satisfactory, however, poor controlling instruments or improper control of drying conditions on the part of the operator will give equally unsatisfactory results.[2]

The proper operation of a dry-kiln is a highly technical occupation. Human and mechanical elements must be balanced and regulated to produce good results. It is important that the kiln engineer be familiar with the mechanical equipment and the characteristics of the lumber to be dried.

Forced Circulation. Forced air circulation in a dry-kiln may be obtained to a limited degree by an injection of a water spray or a steam spray. Fans, of either the internal type or the external type, are usually used to stimulate circulation. There are many types of these fans in use, but all are designed to move as much air as possible through the kiln charge. Moisture cannot

---

2. *Ibid*, page 2.

be extracted from the lumber without air circulation. The moisture laden air must then be withdrawn or forced out of the kiln room.

Heat Conduction. The heat conduction type of dry-kiln is not considered very satisfactory and is seldom used. The kiln charge is stacked on the steam coils to a specified number of layers, then another series of coils is used on which more lumber is stacked. This series of layers of lumber and steam coils continues to the desired height. The heat, from the coils, dries the moisture from the lumber and the moisture is carried away by natural circulation through vents in the roof. The humidity cannot be controlled and the lumber near the coils will become overheated and damaged by too rapid drying.

TYPES OF DRY-KILNS

Dry-kilns may be grouped or classified in a number of ways. When considering the manner in which the charge is handled within the kiln, it may be classed as a progressive or a compartment kiln. The principle involved in establishing and maintaining conditions is much different. The results obtained from employing these factors vary greatly.

Progressive Kiln. The progressive kiln charge consists of a number of truckloads of lumber, each in a different stage of drying. As the lumber is dried, one or more truckloads of lumber are removed from the dried end and other trucks are moved toward that end and trucks of green lumber are moved in to fill up the other end. This process is repeated until the charge has progressed from the green end of the kiln to the dry end. Venting, to remove moisture, is done at the entering end of the kiln where high humidity conditions exist due to evaporation from green lumber. The first end of the kiln is kept at a lower temperature due to the excess amount of moisture being evaporated and less radiation space of the heating coils. Humidity decreases as the lumber moves to the dry end of the kiln and radiation may be increased as the lumber becomes drier. Most progressive types of kilns are of the natural-circulating system type and in these the air circulates longitudinally and vertically. Air may be moved transversely in some forced-circulation kilns.

> A progressive kiln can be used successfully where a constant supply of lumber of the same species, particularly of the nonrefractory species, and of the same thickness is available for kiln drying, and where the final dried lumber need not be free of internal stresses.[3]

The final conditioning treatment, to relieve lumber of drying stresses, cannot be given in a progressive kiln and it should not be used when these conditions must be met. This type of kiln is used mostly where there is a constant supply of lumber of one species and size to be dried.

---

3. Ibid, page 4.

Compartment Kiln. Most modern kilns are of the compartment type which is fully loaded at one time, and the entire charge remains in place throughout the drying time. The drying conditions are kept as nearly uniform throughout the kiln as possible. These conditions are varied during the drying process. Compartment kilns are of three types: natural-circulation, forced-circulation, and conditioning kilns.

Natural-Circulation. Natural-circulation type compartment kilns can be constructed at a lower cost than the forced-circulation type, but more time is required to dry a charge of lumber because of the slower circulation of air. The air is circulated by natural means, the hot air rises and the cool air falls. Cool fresh air enters the kiln from the outside through fresh air ducts, passes over the heating coils, becomes lighter and rises through the vertical "A" flues provided by proper stacking. They are, however, some opposing air forces between the hot air and cool air which hinder proper circulation resulting in wet spots in the kiln charge.

Forced-Circulation. Forced-circulation compartments may be classified into water-spray, internal-fan, external fan, external blower, and internal blower types. Air circulation in the water-spray kiln is induced by water-spray jets that move the air through the heating coils and upward through the "A" flue in the kiln charge, then transversely to each side of the charge and downward between the sides of the charge and the kiln walls. The temperature of the water can be controlled to keep kiln conditions proper. Air circulation in this type kiln is positive, but slow. This type kiln is seldom used at present.

Short-shaft Internal-fan Kilns. Short-shaft internal-fan kilns are equipped with individually motor driven fans which may be located either above or below the load. These kilns may use cross-piled or end-piled methods. In cross-piled kilns the air is moved from the fan the full length of the kiln through baffled air ducts and returned to the fan through a return line where it is heated and re-circulated. Vents in the kiln permit the escape of hot humid air and the entry of cool dry air. Control bulbs are located below the track level. Reverse-circulation can be accomplished by changing the rotation of the fan.

Long-shaft Internal-fan Kilns. The long-shaft internal-fan kiln may be of the same type as the short-shaft kiln except that all of the fans are mounted on one long shaft which runs from one end of the kiln to the other. The shaft and fans are operated by a single motor mounted outside the kiln at either end. This fan is of the reversible type so that the directions of the air circulation can be reversed to insure proper drying conditions. This type of fan requires a system of baffles to divert the air flow in a longitudinal direction. One half of the fans are right hand fans and the other half are left hand fans. The baffles are arranged diagonally and change direction at the center point between the right-hand and left-hand fans. The two center fans oppose each other, blowing toward each other when rotated in one direction and away from each other when the motor rotation is changed.

As in the short-shaft system, these fans may be mounted above or below the kiln charge. The heating coils may also be located above or below the load. Baffles must be provided below the fans in case of overhead fans or above when fans are located below the track. An opening about thirty inches wide should be provided between the baffle and wall of the kiln. These fans may be used for single-track or double-track kilns. When used on double-track kilns, a booster coil is added between the tracks to reduce the temperature drop.

External-blower Kilns. The external blower type kiln may be of the single-track or double-track type. The heating and fan units are located outside of the kiln, usually at one end. The air is forced into the kiln through air ducts located under the "A" flues of the lumber charge. The air is forced up through the "A" flues and out through the layers of lumber, then back to the fan unit through return ducts loacted in the floor near the walls. The returned air is reheated and then recirculated through the charge. Ventilator stacks are provided in the blower housing to expel hot moist air, which is replaced by cool dry air through fresh air doors.

Some external blower kilns are constructed so that the air circulation can be reversed, forcing the air up through the outside plenum chambers, through the charge of lumber, and back through the "A" flue. Conditions are controlled from the entering air ducts of the kiln.

Furnace-type Internal-fan Kilns. The internal-fan furnace-type kiln is heated by a large smoke pipe which passes back and forth and up along the length of the kiln, then to a chimney in the roof. The fans blow the air across this smoke pipe, which is heated by the furnace, to one wall, then through the lumber, from where it is returned to be reheated. The humidity is maintained by a steam spray line, controlled automatically or manually.

It is difficult to make recommendations as to the type of dry-kiln to install without making a thorough study of all the conditions involved. It is probably advisable to locate as much of the machinery outside of the dry-kiln compartment as possible because of the damage that may be caused from acids and moisture given off by the lumber as it is being dried. It is possible to purchase motors and other equipment that give satisfaction when used inside the kiln. Motors and equipment located outside the kiln can be serviced by the engineer during kiln operation times with less discomfort than those located inside.

Availibility of material and labor, as well as local building codes, may determine the type of building to be constructed. Prevailing temperatures and other weather conditions must be considered when choosing building materials and types of construction.

CHAPTER IV

DRY-KILN BUILDING MATERIALS AND CONSTRUCTION

The builder of a dry-kiln should have in mind a number of conditions peculiar to the locality before making a decision concerning the type of installation chosen. Specifications may be secured from manufacturers of dry-kilns to guide the builder in making this choice. These companies will readily give the builder the advantage of their experiences in building the structure and selecting the necessary machinery for efficient operation. The type of equipment desired should be selected and the plans of the building should be checked by the kiln equipment manufacturer for details to determine whether or not the equipment is suitable for the building.

GENERAL CONDITIONS

Materials suitable for dry-kiln construction are more or less limited to wood, concrete, concrete-blocks, brick, and terra-cotta tile. Other materials such as fiberboard, and asbestos cement board are sometimes used. Steel is used for tracks, fans, fan supports, heating coils, baffles, and other such parts. Some steel is used for structural parts and as reinforcement of concrete parts. For desirable results, exacting requirements must be met in structural details.

Since dry-kilns are subjected to severe

moisture and heat conditions both inside and outside, they can be expected to be shorter-lived than most structures.

> They not only have to withstand weather, but also the action of high temperatures and humidities, the expansion and contraction caused by frequent and wide changes in temperature, and frequently the corrosive action of acid vapors from the woods that are being dried. To be efficient, the kiln walls and roof must be reasonably resistant to transmission of heat.[1]

The selection of materials for the building may be governed by a number of factors. Local building codes may require a certain type of building made of fireproof material. Insurance rates may prohibit the use of wood as a building material. Other principal considerations in the selection of building materials are durability and availability, labor supply, investment required, and climatic conditions.

Concrete should always be used for floors, foundations, and wall sections below ground level. Specifications for concrete should be prepared by a resident engineer to meet local requirements. Steel reinforcement should be provided to strengthen the concrete.

---

1. Dry-Kiln Building Materials and Construction, U. S. Forest Products Laboratory Bulletin No. R 1646, Page 1.

Lumber is often used for other structural parts in localities where there is an abundant supply. Masonary may be used for walls with wood for roofs. Pine, douglas-fir, spruce, cypress, and redwood are commonly used for walls and roofs due to their ability to resist decay. A wooden structure usually has a lower initial cost and is easy to repair when necessary. There is also a high resistance to heat loss, but the fire risk is great.

Brick, concrete, concrete blocks, and tile are fireproof, but are subject to damage caused by expansion and contraction. There is a rather high rate of heat loss in solid masonary walls and roofs. The porous condition of such structures and the cracks which appear from expansion and contraction cause difficulty in controlling the humidity in the kiln. Hard-burned brick or load-bearing terra-cotta tile are excellent wall materials. All large masonary type buildings should be constructed with expansion joints.

STRUCTURAL DETAILS

Proper design and specifications must be carefully followed in the construction of a dry-kiln to insure satisfactory results. Good kiln engineering practices and construction must be adhered to because of the severe conditions to which the building is subjected.

Subfoundations. Much of the serviceability and life of a structure depends upon the subfoundation or footing. The requirements for this portion of the building can be determined by the soil conditions and type of structure to be built. The footings must be adequate to support the weight and strong enough to withstand changes of soil expansion and contraction during seasonal changes. Any subfoundation failures caused by natural conditions will result in other structural damages. In addition to building damages resulting from cracks, temperature and humidity control will be difficult. The tracks may get out of alignment and cause truck handling difficulties. Footings requirements should be established by a resident engineer.

Foundations. Reinforced concrete should be used for all foundations and should be designed to carry the load placed upon it. Waterproof concrete should be used where ground water will be encountered. The foundation should extend at least six inches above ground level. Where wooden walls are erected, the thickness of the foundation should be about ten inches. For masonry walls, the foundation should be the same thickness as the walls. Expansion joints should be provided in foundations where the span is forty feet or more.

Floors and Tracks. Most dry-kilns have reinforced concrete floors about four inches thick. They may be level or may contain pits depending upon the type of equipment used. Where under-track equipment is used, provisions must be made for installation. Some floors contain steel gratings to permit air circulation. As a safety factor, floors should be as nearly level as the installations will permit.

Tracks for trucks should be set in the floor at the time that the concrete is run. The tracks should be made of thirty five pound per foot steel railroad rails, and be set with the tops level with the floors.

Walls. The walls should be made of material strong enough to support the roof and any machinery that may be installed above them. The walls should be good heat insulators and resistant to vapor transmission. All partition walls separating adjacent kiln compartments should be constructed to satisfy these same conditions.

Wooden Walls. Where wooden wall construction is used, the studs should be two inches by six inches, and set on sixteen inch centers. The inside should be covered vertically with vapor-proof building paper. The outside sheathing should be shiplap or center-matched material covered with drop or beveled siding. Insulation material should be used to fill the space between the studs.

Slow-burning walls are sometimes used where lumber is plentiful and cheap. These walls are constructed by nailing together two inch by six inch stock laid flat, one piece above the other. Buildings thus constructed usually carry a lower insurance rate. They are also slow to transmit heat and vapor.

Concrete Walls. Poured concrete walls are seldom used in dry-kiln construction because of heat and vapor loss and damage caused to the walls by expansion and contraction. Where they are used for any reason, such as availability of material, they should be well reinforced with steel and made of a standard mix. Outside walls should be twelve inches thick and inside walls should be eight inches thick. One-half inch vertical expansion joints must be provided for each forty feet in length. Pilasters should be included in the walls at twenty foot intervals. The walls should be coated on the inside with insulating and vapor-resisting material.

Concrete-Block Walls. Some kilns are built of concrete-blocks. These blocks should be made of cement, sand, and some aggregate. Cinders, burned-clay, or slag provide some insulating properties; however, crushed stone, which is a poor insulator, is sometimes used. A more recent aggregate that is used, but has not been tested thoroughly is pumice. This is light in weight and is a good insulator. All concrete blocks should be of hollow construction. Tempered mortar should be used to bind the blocks together. These walls should be plastered and covered with vapor-proof insulating material on the inside.

Brick Walls. Dense, hard-burned brick laid in tempered mortar makes one of the most satisfactory walls used in the construction of a dry-kiln. The wall should be thirteen inches thick, and strengthened with pilasters spaced twenty feet apart. A good kiln paint should be applied to the inside of the wall.

Terra-cotta Tile. Where terra-cotta tile is used, it should be of the dense and hard-burned load-bearing type. Walls should be twelve inches thick and laid with tempered mortar and pilasters should be used at twenty foot intervals. The inside of these walls should be painted with kiln paint.

Kiln Paint. Kiln paint should be used on the inside of all kilns to reduce the loss of heat and vapor. This paint will also protect any metal used in the construction from the corrosive action of the acid given off in lumber drying. This coating will also help protect the mortar used in masonary buildings. This paint is of the mastic type and should be applied as often as needed to keep a good protective coating on the walls.

Roof and Ceiling. It is difficult to construct a roof on a dry-kiln that has all of the desirable qualities. It should be nearly flat, but must have sufficient pitch to drain well. It should be strong enough to support itself and any machinery or control tower that may be located above it. Heat and vapor resistance are factors to be considered. The underside of the roof should be a uniform distance from the kiln load to give proper air circulation where a separate ceiling is not provided.

Where a suspended ceiling is provided below the roof, it should have sufficient air space and ventilation to remove moisture which passes through it. The roof could possibly be insulated with less expense then a separate ceiling when a slab roof is used. It is possible to remove moisture from the ceiling with a series of steam pipes installed directly beneath it.

Wooden Roofs. A wooden roof on a dry-kiln is usually short-lived, because of the hazard of decay, resulting from excessive vapor. Where wood sheathing types of roofs are used, they should be supported by two inch joists placed on sixteen inch centers. These may be covered with one inch material which is covered with a vapor barrier consisting of roofing paper mopped with asphalt. On this should be placed another layer of two inch planking which is covered with composition roofing. The exposed joists interfere with air circulation in the kiln where a ceiling is not provided.

The most satisfactory wooden roof is made of the laminated or slow-burning type where two inch by eight inch stock is laid on edge, nailed firmly together, and covered with composition roofing. This requires a large amount of material, but provides good insulation.

Reinforced-concrete Roof. The roof may be made of a slab of reinforced concrete if desired. Due to the heat and vapor loss through this roof, it should be covered with a vapor barrier of building paper mopped with asphalt, and then covered with two or three inches of insulating material topped by a composition roof. Expansion joints must be provided on large slab roofs.

Tile and Concrete Roofs. Terra-cotta tile, supported by concrete beams, is sometimes used as a roof. This should be provided with vapor proofing and insulation as described for slab roof. Expansion joints must also be provided.

Doors. The efficiency of a well constructed and adequately equipped kiln can be greatly reduced by poor doors. Doors should be made as light in weight as possible, but still have good insulating qualities. They may be made of a steel framework covered with two or more layers of one inch wooden material and are sometimes covered with sheet metal.

Patented hinges and tracks are usually used on kiln doors. Swinging doors are not considered very satisfactory. A small inspection door should be provided in the kiln so that the large door can be kept closed while the kiln is in operation and the charge is being inspected.

Control Rooms. The control room should be made of sufficient size to house all instruments used in checking or operating the kiln. It may be located at any convenient place about the kiln. Where machinery is located on top of the kiln, it may be advisable to have the control-room on top of the roof. All testing equipment and records should be kept in this room to insure more efficiency.

The building material could be of any type, but it is more desirable to have it made of the same material as the kiln. This should be the kiln engineer's laboratory.

The most expert kiln engineer with the most modern kiln equipment cannot do satisfactory drying of lumber if the building is not properly designed, constructed, and maintained. The location and the climatic conditions will have a great bearing upon the type of kiln construction and the kind of building material that should be used.

CHAPTER V

TEMPERATURE MEASURING AND CONTROLLING DEVICES IN LUMBER DRY-KILNS

It is very important that an accurate measurement of wet-bulb and dry-bulb temperatures in a dry-kiln can be recorded and controlled for efficient operation. All controls and instruments are calibrated on the Fahrenheit scale.

PRINCIPLES EMPLOYED IN MEASURING TEMPERATURES

Five principles employed in measuring temperatures in a dry-kiln will be considered in this chapter.

Liquid-expansion Thermometers. Liquid-expansion thermometers are very often used for temperature recordings. These thermometers are generally filled with mercury, although other fluids, such as hydrocarbons, are not uncommon. Mercury filled thermometers may be successfully used with temperatures ranging from -35^{o} to $1{,}000^{o}$ F.[1]

Gas-expansion Thermometers. Gas-expansion thermometers have a range from about -200^{o} to 800^{o} F. Nitrogen is the most common gas used as a filling medium and operates on the principle of Charles' Law. The scale of a gas-expansion thermometer is not linear and must be compensated to provide a linear calibration.

---

1. Temperature Measuring and Controlling Devices in Lumber Dry-Kilns, U. S. Forest Products Laboratory Bulletin No. R1654, page 1.

Vapor-actuated Thermometers. Vapor-actuated thermometers utilize vapor pressure to actuate the indicating element. The vapor pressure of a liquid varies with temperature in accordance with the laws of thermodynamics. The most common filling media for vapor-actuated thermometers are sulfur dioxide, ether, methychloride, and tuluene. The range of temperatures is usually from -50° to 600° F.[2]

Thermal-electrical Thermometers. Thermal-electrical thermometers employing the change in an electrical characteristic may be used to measure temperatures. Two dissimilar wires welded together at one end are known as thermocouples. When the temperature at the welded ends change, an electrical potential is generated in the circuit, and this can be measured by a potentiometer connected to the free ends. Wires used in making thermocouples for measuring temperatures in dry-kilns are usually copper and constantan.

Bimetallic Thermometers. Bimetallic thermometers are constructed by welding or soldering together two metal strips having different coefficients of thermal expansion. The change of temperature can be indicated as the bimetallic strip deflects from one side to the other, thus operating an attached controlling arm.

---

2. Ibid, page 2.

TYPES OF THERMOMETERS

Thermometers of three types are used in measuring dry-kiln temperatures. They are indicating, maximum-reading, and recording.

Indicating Thermometer. The indicating thermometer is constructed of a glass stem, with a bulb at the bottom, containing the fluid which when expanded by heat registers the temperature on graduations etched on it. A thermometer attached to a metal strip with readings stamped on it is not reliable due to the chance of the stem's changing positions on the calibrated strip.

Maximum-reading Thermometers. Maximum-reading thermometers may be used to measure the highest temperature existing in the kiln. It is similar to the clinical thermometer and does not register the retarding temperatures.

Recording Thermometers. Recording thermometers are of the extension-tube type where the sensitive element or bulb is connected to the instrument by a capillary tube. Three types of these instruments are suitable for dry-kiln use, and may be filled with mercury, gas, or vapor. The gas filled recorder is ordinarily used. These thermometers may be calibrated similar to the glass tube thermometer and adjustments may be made by changing the position of the recording arm by means of a screw provided for that purpose. Wet-bulb recorders and dry-bulb recorders should be calibrated at the same time. A longer time will be required to get an accurate reading on this type of instrument due to the lag in the change of conditions in the longer tube. Adjustments should be made when conditions are as near as possible to operating conditions.

Calibrating Thermometers. A thermometer may be calibrated by comparing it with one known to be accurate. This is most accurately done by using a standard twelve inch mercury-filled indicating thermometer with numbers etched on the stem. A thermometer is calibrated by placing it in cold water with a standard thermometer, and taking the readings on both instruments. Heat the water and take readings, at intervals, on both thermometers. The difference in the readings of the two instruments will indicate the error of the one being tested and the correction can be made. A plus correction is made when the standard reads higher and a minus, if the reading is lower. If a standard thermometer is not available, a number of thermometers may be used, and the average of them can be considered as fairly reliable.

MEANS OF CONTROLLING TEMPERATURES

Temperatures must be controlled in a dry-kiln to give proper drying conditions. The older types of kilns may use a manual control system while all modern kilns are equipped with automatic control systems. It is necessary to use automatic control where a rigid drying schedule is to be maintained. Greater variations in conditions must be expected where manually operated equipment is used even when an operator is in charge at all times.

Manual Control. Manually operated heating valves are used to furnish the desired temperatures for some kilns. Unit heaters may be provided which are supplied with heat from constant steam heat. It is necessary to have an operator on duty at all times to regulate the flow of air through these heaters. When cold or warm conditions exist outside of the kiln, it is necessary to regulate louvers in the kiln and in the air flow from the outside to maintain uniform conditions inside. When the weather is cold, a large amount of heat is lost by radiation through the kiln walls, and also more heat is required to bring the outside air to meet kiln temperatures. In hot weather, the conditions are reversed.

When heat is furnished by steam coils located within the kiln, it is very difficult to maintain proper temperatures because the amount of steam pressure is difficult to control. This can be accomplished to a certain extent by using steam reducing valves. It is never advisable to attempt to control the steam flow into the coils by regulating valve openings. The valve should be completely opened or closed, or it will be damaged by grooves being cut in the partly opened valve by the steam flow. When these valve seats have been damaged, it is impossible to control the flow of steam.

Automatic Controls. Most modern dry-kilns are equipped with self-contained or air-operated automatic controls. Self-contained thermostats are operated by direct action of vapor and liquid pressure on a diaphragm motor which operates the valve stem. Air-operated thermostats do not react instantaneously to temperature changes, and a variation of temperatures can be expected.

In the various types of automatic controlling instruments thermostats are used to control temperatures in dry-kilns, but usually they are incorporated with more elaborate equipment such as a recorder-controller.

Most thermostats in dry-kilns employ a capillary-tube and a bulb that contains a liquid vapor or gas. Thermal expansion and contraction and pressure changes within the closed system are used either directly, as in the self-contained type, or indirectly, as in the auxiliary-operated type, to operate a diaphragm valve on the heating system.[3]

Self-contained Thermostats. Self-contained thermostats combine in a single unit a valve and the fluid containing system, consisting of the bulb, the capillary

---

3. Ibid, page 3.

connecting tube, and motor head. Pressure inside the bulb changes with variation of the temperature of the kiln, which in turn causes corresponding pressure changes in the motor head. This action opens or closes the valve which is controlled by the diaphragm. The valve is a very sensitive instrument, usually balanced to insure free action, and may be regulated by means of springs or weights.

The self-contained thermostat requires no outside source of power, and is inexpensive to install; however, it is not as quick to respond to temperature changes and will not withstand a varied steam pressure.

The self-contained thermostat is of most value in the progressive type kiln where the temperature is kept constant, and the motor head is not subjected to a temperature change that occurs in a compartment type of kiln.

Auxiliary-operated Thermostat. The auxiliary-operated thermostat depends upon some outside source of power to operate the steam valve. Power for operation of valves is obtained from electricity, water or steam pressure, or compressed air, or a combination of two or more of these forces. This type of thermostat is more sensitive than other types, and will hold the temperature range to about one degree Fahrenheit, where ample air circulation is provided. It is composed of the extension-type tube with bulb, capillary tube, and pressure-sensitive hollow spring or capsule filled with a liquid and its vapor.

Either dry-bulb or wet-bulb temperatures may be controlled by a thermostat. The bulb is covered with a wick which is supplied with water from a tank to give a wet-bulb reading.

Recorder-Controller. The recorder-controller is a combined thermostat and recorder in which the temperature-sensitive element regulates the air supply to the diaphragm-motor valve and also moves the recording pen arm. These instruments are equipped with a wet-bulb and one or more dry-bulbs. Two dry-bulbs are usually used in reversible-circulation compartment dry-kilns to insure a more rapid adjustment of the heat supply. The bulb located in the highest temperature zone will be the controlling bulb. Some recorder-controllers also operate an automatic vent system by means of attaching a controlling mechanism to the helical spring of the wet-bulb control.

Since the recorder-controller instrument is small and is operated from only one area of a dry-kiln, it is impossible to have all conditions perfectly controlled. The bulbs sho ld be placed in the hottest spot of the kiln. It can be determined by taking temperatures at various places in the charge, so that the lumber will not have an excessive amount of degrade from too rapid drying. Bulbs should always be placed on each side of the charge, about midway between the floor and the ceiling and near the center from end to end.

When external-blower types of kilns are used, the dry bulb should be placed in the hottest part of the "A" flue, if possible. Where this is not possible, the bulb may be placed in some other part of the kiln; but an adjustment must be made for the heat loss from the entering air part and the location of the bulb. The difference in these temperatures can be determined by using maximum-reading type thermometers.

CHAPTER VI

A PROPOSED DRY-KILN FOR THE OKLAHOMA AGRICULTURAL AND MECHANICAL COLLEGE

Efforts are being made to construct and equip a modern dry-kiln at the Oklahoma A. & M. College. This project is being sponsored by the Department of Industrial Arts Education and Engineering Shopwork. Much interest and support are given by the Department of Forestry. This proposal includes the aspects of offering courses of instruction in the operation and maintainance of modern dry-kilns. A supply of properly dried lumber can be provided from the school shops and commercial manufacturers. The management of the dry-kiln would be assumed by instructors in the Cabinet Shop which would use a part of the lumber dried. This kiln will be of sufficient size to dry one truckload of lumber which is about six thousand board feet. Custom drying could be done to provide a continuous operation and help pay the cost of operation.

The dry-kiln location is adjacent to the Cabinet Shop at the northeast corner of the southeast wing of the building. This location was chosen because of the convenience of operation and handling of materials.

THE BUILDING

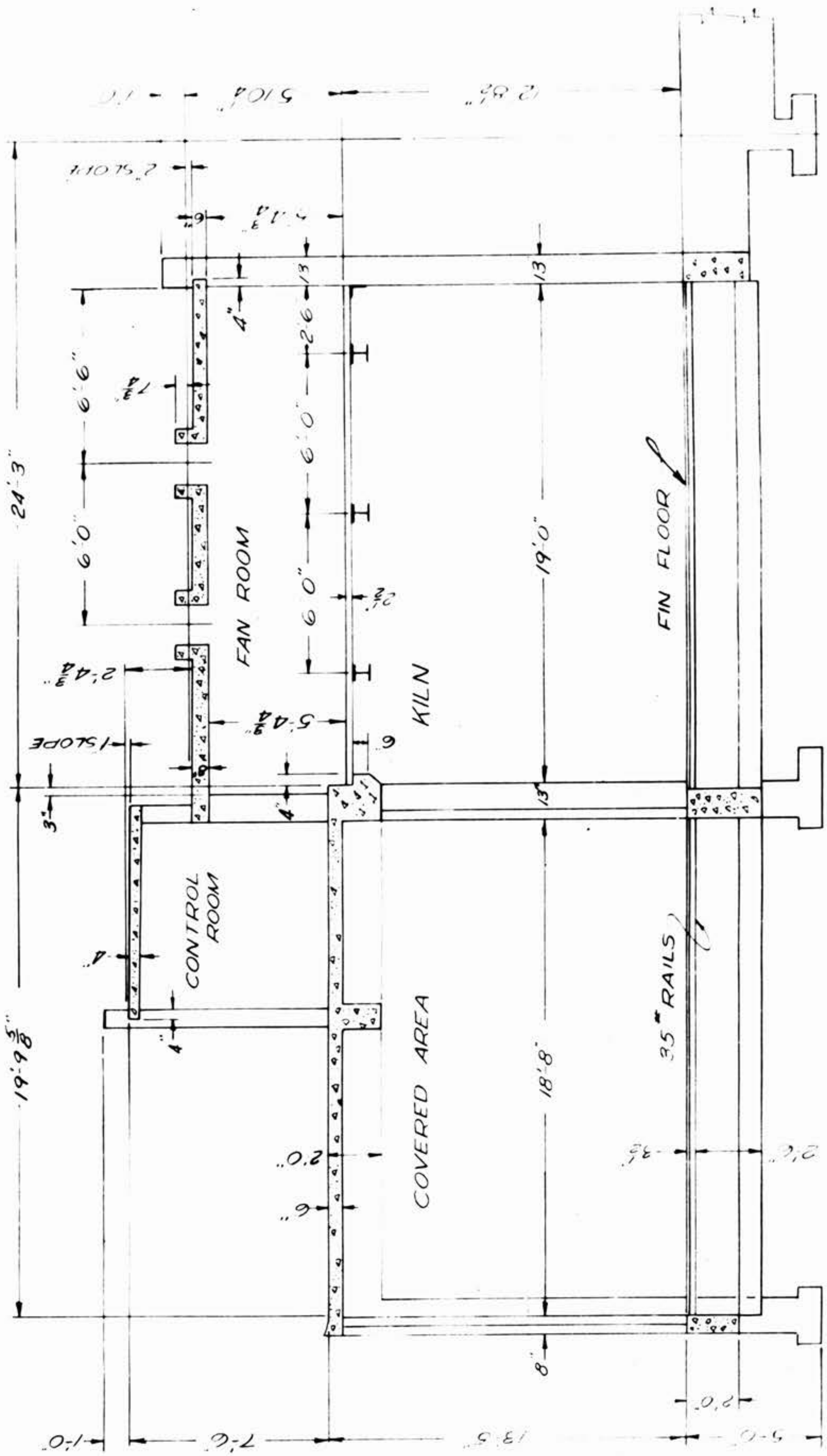
This dry-kiln is to be an annex to the present

Industrial Arts Building which is made of red brick. It is in keeping with the main architectural plan. This building plan furnishes desirable loading and unloading facilities for handling green and dried lumber, and is convenient to storage space for dried lumber. Plates No. I and No. II of this chapter represent the proposed plans of this building.

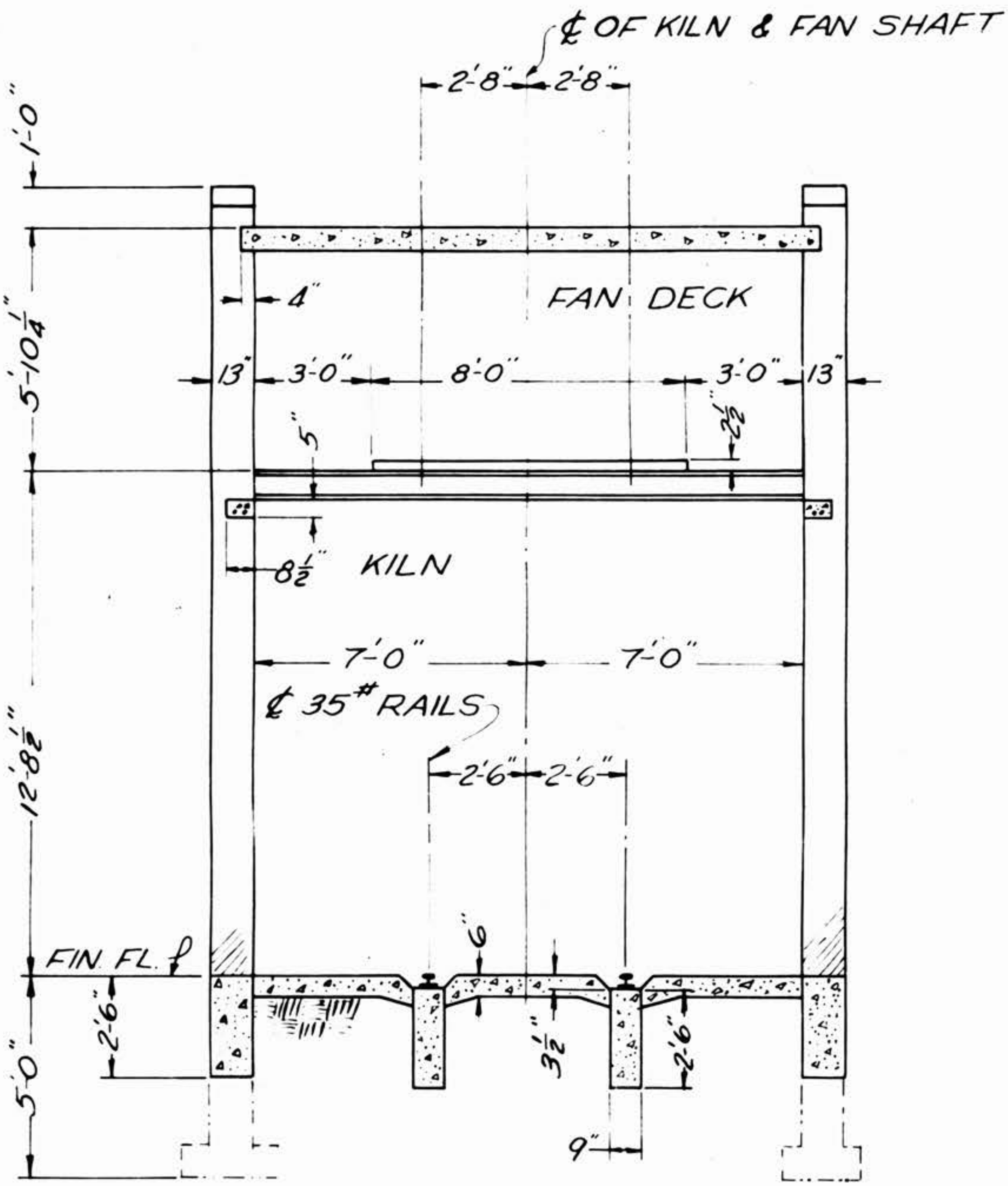
Subfoundation. The subfoundation or footing plan calls for reinforced concrete made of a standard mix of one part of cement, two parts of sand, and four parts of crushed stone. One-half inch reinforcing steel, placed on six inch centers will be used in the footing. The subfoundation will be one foot thick, twenty-four inches wide and four feet deep.

Footings under the columns supporting the concrete slab above the loading area will be one foot thick, two and one-half feet square and five feet deep, and contain one-half inch reinforcing steel placed on six inch centers. Continuous footings under the rails are to be nine inches thick, twenty-four inches deep and contain two one-half inch reinforcing bars.

Foundation. The foundation will extend six inches above ground level and will be made of reinforced concrete. The mix of one part of cement to two parts of sand, and four parts of crushed stone will be used for the foundation. One-half inch reinforcing steel bars are to be placed in



PROPOSED DRY KILN - OKLAHOMA A&M COLLEGE
PLATE I



A PROPOSED DRY KILN · OKLAHOMA A.& M. COLLEGE
PLATE II

the concrete to provide added strength. The foundation will be thirteen inches thick.

Floor and Tracks. The floor of the kiln will be made of reinforced concrete four inches in thickness. This floor will extend two inches above the ground level to eliminate surface drainage from entering the kiln. The tracks for trucks are to be placed in the floor at the time the concrete is poured. These tracks will be made of thirty-five pounds per foot railroad rails. Only enough depression should be made in the concrete on each side of the rails to permit free passage of the flanges on the truck wheels. A level floor of this type makes a safer working surface.

Walls. The walls are to be made of dense, hard-burned brick set in tempered mortar. These walls will be thirteen inches thick and eighteen feet and six inches high. The width of the kiln will be fourteen feet and the length twenty feet. The structure is to be joined to the main building by removing part of the brick and inserting the brick in the new wall. A portion of the wall of the existing building will serve as one wall of the kiln.

Fan Deck. A two and one-half inch thick reinforced concrete fan deck supported by three, eight inch I-beams, will be provided through the center of the kiln from one end to the other. This deck is to be eight feet wide leaving a three foot open space on each side. Anchor bolts will be set in the slab for installing the fans and baffle system. A clearance of five feet and five inches between the ceiling and the deck is required for the fan system.

Roof and Ceiling. The roof will be made of a reinforced concrete slab resting on the top of the brick walls. The roof is to be eight inches thick at the main building and will decrease to six inches at the outside edge. This provides a two inch drop to insure proper drainage and also provides a level ceiling. The slab will be covered with roofing paper and mopped with asphalt to provide a vapor barrier. Three inches of sheet cork insulation will be placed on top of the vapor barrier. A composition roof will be laid over the insulation. Bolts and flanges used for the installation of machinery and equipment are to be placed in the concrete at the time it is poured. Openings for ventilating equipment are provided in the roof.

Doors. The main door of the kiln is to be eleven feet wide and eleven feet high, and constructed of two layers of laminated wood covered with sheet aluminum and bound on the edges with steel channels. A vapor seal will be provided between the layers of wood. Special patented hangers and door track are provided for points of contact between the door and building. Any air leakage around the door will unbalance the drying conditions inside the kiln.

An inspection door should be provided in any dry-kiln. This door is often located in the main door, but in this case, it is recommended that it open from the southeast corner of the present lumber storage room. This location is more convenient for the operator and conditions inside the kiln will not be affected as noticably as if an outside door were provided. This door should be of the same type of construction as the main door, but may be hinged to the door frame.

There will be a tight fitting steel door between the control tower and the kiln. This door will give access to the fan and baffle installations on the deck.

<u>Control Tower</u>. The control tower is to be built above the slab covering the loading dock. A part of the slab will serve as a floor for this room. The rooms will extend the width of the kiln and eight feet and four inches to the south, giving a seven foot inside measurement. This tower will have eight inch walls and a four inch roof. Two, thirty inch by thirty-six inch windows will be provided in the south wall and one in the east wall. The door is to be located in the west wall and deck door in the north wall.

All instruments and control panels will be housed in the control tower. This is to be the kiln engineer's laboratory and office.

Wall and Ceiling Coating. A special kiln wall paint should be applied to the walls and ceiling. This paint is of the mastic type and has good insulating qualities and also retards vapor transmission. This coating should be about one-fourth inch thick and should be renewed as often as conditions require. Under normal operating conditions paint will last on the ceiling and wall from one to two years.

Loading Area. The loading area will consist of a concrete slab six inches thick, fifteen feet wide and twenty feet long. It will be reinforced with one-half inch steel bars placed on six inch centers. A track to the kiln is to be set in this slab on a nine inch by twenty-four inch footing and a switching track provided to enter the double door of the Cabinet Shop.

The overhead slab will be six inches thick and supported at each corner with a twelve inch by twelve inch concrete column. Concrete beams between columns will measure twelve inches by twenty-four inches. These beams will support the weight of the deck and control tower.

EQUIPMENT

The most expensive and elaborate dry-kiln building operated by an expert dry-kiln engineer will not give satisfactory drying results without the proper equipment. The building and the equipment should be designed and made for each other. The efficiency of one depends largely upon the other.

Equipment recommended for the dry-kiln proposed for the Oklahoma A. & M. College is of the most modern type. When considering requirements for equipment to be used as an aid to instruction, and for experimentation and research the most efficient should be selected. This equipment should be capable of properly drying any type of lumber that might be selected. Ideal conditions should be established in order to demonstrate effectively, the principles of the operation of a kiln.

Heating Unit. Steam heat is to be furnished from a high pressure steam line direct from the central power plant. This steam pressure will be regulated by a steam pressure regulator to maintain a steady supply of heat. The condensate from the coils will be returned to the power plant through a return line. A steam pressure of twenty-five pounds per square inch will be maintained at all times.

Coils. The steam coils used to supply heat for the kiln will be made up of sixteen pieces of one and one-fourth inch finned pipe, eight feet long. These pipes will be welded to steel headers and arranged so that there are two coils containing eight pipes each.

The coils will be placed horizontally across the opening at one side of the fan deck so that heat will be furnished to the lumber from the flow provided by the fans. The coils should have a drop of one-fourth inch per foot from the feed line to the discharge line to insure proper drainage. When reverse circulation is desired, the air flow will come from the kiln charge through the coils where it is reheated; then to the fans and down the opposite side of the kiln and through the lumber again. When straight circulation is desired, the air flow follows the opposite direction passing over the coils from the fans.

Headers. The headers used to make up the supply and return feeders for the coils are to be made of four inch steel pipe and welded to the finned pipe. Welded construction will eliminate the use of unions for connecting the pipes. The feed and return pipes should be inserted at the longitudinal center of the headers, and at a right angle to the coil. The supply line should enter at the top of the header, and the drain line should enter at the bottom of the return header.

Steam Traps. One steam trap should be installed for each coil, to collect and return the condensate to the return line. These traps must be of sufficient size to dispose of all condensate produced by the coils, and should be placed below the coils where they are fed by gravity. The traps should be placed where they can be easily inspected and cleaned when necessary. A gate valve should be provided in each line ahead of a trap to provide a means of closing the discharge line when the trap is cleaned.

Reducing Valve and Check Valve. A steam reducing valve is required where there is a variation of as much as twenty-five percent in steam pressure. This is placed in the steam line before it enters the feeder header. A constant steam pressure will provide a more uniform temperature. A check valve should be provided in the return line, above the steam trap, to prevent condensate from re-entering the coil when a vacuum is formed.

Fans and Baffles. Four fans are to be mounted on one shaft driven by a motor located in the control tower. These fans are to be sixty inches in diameter, have four blades each, and be located so that they are equally spaced above the fan deck. Two fans are to be right hand fans, and the other two are to be left hand fans. They will be located so that number one fan and number two fan will oppose each other, and number three and number four will likewise oppose each other.

Baffles will be arranged so that each fan is placed in an opening in a baffle. One end of the baffle on number one fan will be connected with another baffle at a ninety degree angle, which extends to the end of the kiln. The other end of the baffle connects to the corresponding end of the fan baffle on number two fan. The second and third fans are connected in like manner and also three and four fans. Number four is then baffled to the other end of the kiln. All baffles reach from the fan deck to the ceiling of the kiln to keep the air from short circuiting.

Number one and number four fans are fed by air from the ends of the kiln and numbers two and three are fed from the baffled section between them. This causes the air to flow from one side of the kiln to the other, then down on one side of the lumber, through the lumber and return on the other side of the fan deck where it will be reheated by the steam coils, and then back to the fans. When the direction of the fans is changed, number one and number four fans force the air out through the end baffled sections. Number two and number three fans oppose each other and drive the air from the center baffled section. The air passes from the fans over the heating coils, then down the side of the kiln, and through the lumber. It then returns up the opposide side of the kiln and back to the fans where it is re-circulated.

Motor and Switches. The motor should be a 220 volt, 3 phase, 60 cycle, and must develop five horse power. An ordinary first grade motor may be used as it is located outside of the kiln. It should be equipped with a V belt drive with pulleys to give a fan speed of 1,750 R. P. M. This motor is to be located below the pulley on the drive shaft of the fans and the belt should be guarded.

The switch should be a fully automatic time lag double throw reversing switch controlled by the recorder-controller clock. This switch should have an automatic cutout for overload and underload voltage conditions. A manual control switch should be provided in the line ahead of the automatic switch so that the current may be cut off in case work is to be done on the motor or fans.

<u>Ventilating Equipment</u>. The kiln should be equipped with an automatic ventilating system. This system will operate from the wet-bulb arm of the recorder-controller. When the relative humidity becomes too great in the kiln, the vents will open, allowing the escape of hot moist air and the entrance of cool moist air. This regulates the relative humidity and the temperature. If the dry-bulb temperature is too great, the supply of heat will be reduced.

<u>Recorder-Controller</u>. The proposed recorder-controller for the dry-kiln to be installed at the Oklahoma A. &. M. College will be of a type that contains two thermostats and a recorder. One thermostat will operate from the dry-bulb arm of the recorder and will regulate the temperature of the controlling dry-bulb. The other will

be attached to the recording arm of the wet-bulb and will regulate the damper system and the humidity injection system.

There will be one wet-bulb located near the center of one wall. It will be placed midway between the ceiling and the floor, and also midway from one end to the other. This bulb will be provided with a wick supplied with water from a tank attached to an outside supply of water. The recording pen arm will control the air operated valve to the damper system so that it will open when the humidity is too great. It will also control the valve to the steam injection system to add moisture when the humidity is too low.

There will be two dry-bulbs attached to the recorder. One will be located just above the wet-bulb, and the other one on the opposite wall of the kiln. The bulb on the entering side of the air chamber will always be the controlling bulb due to the drop in temperature as the air passes through the lumber. By having two dry-bulbs, the temperature will be kept more uniform when the fans are reversed. The recording pen arm will control the air valve to the steam line and regulate the amount of heat in the kiln.

The pens on the recorder arms will record the conditions within the kiln on a chart operated by a seven-day clock. This chart will be a diary of the conditions.

of the kiln from hour to hour and from day to day. When it is necessary to leave the charge of lumber in the kiln longer than one week, the second chart can be placed on the recorder to continue the record.

Humidifier. A good drying schedule requires that the humidity conditions of the kiln be under constant control. This is done by the diaphragm-motor valve connected to the steam spray line. This line should be installed the full length of the kiln and supplied with steam spray nozzles. The steam spray line should operate at a lower pressure than the heater line. As the humidity becomes low in the kiln, the recorder arm on the wet-bulb will cause the valve to open and steam will be injected into the circulating air causing the humidity to increase. When the proper conditions are met, the steam valve will be closed by the recorder-controller.

Lights and Wiring. The lights will be vapor-proof and protected by galvanized wire caging. There will be two 150 watt bulbs on each side of the kiln. The wiring will also be vapor-proofed with a metal covering and connected to a switch located on the outside of the kiln next to the door.

Trucks. The trucks used for stacking and moving the lumber will be made of two six foot lengths of four inch channel-iron fastened together with two high-carbon steel axles. On these axles, will be eight inch forged steel wheels with three-fourths inch flanges on each side. The wheels will be equipped with roller bearings. Four of these assemblies will be used for holding one kiln charge. The cross-members between the trucks will be four inch I-beams. Eight trucks will be provided so that two charges of lumber can be piled at one time.

Testing Equipment. It is necessary to provide good testing equipment for a dry-kiln in order to know how to operate it. It is impossible to know how to regulate the kiln without knowing the progress that is being made in drying. The best of equipment is the least expensive if the percentage of degrade can be reduced.

Moisture Meter. An electric moisture meter should be provided to check quickly the moisture content of the lumber going into the kiln. It is necessary to know the percentage of moisture in order to select the proper drying schedule. A sampling can be made of a large number of boards in a short time. This instrument is not accurate enough to govern the drying conditions throughout the entire time, but it can be used to help in selecting the drying schedule.

Drying Oven. A good electric oven should be provided for testing the moisture content of kiln samples. This oven should have a thermostat control to maintain a uniform heat, and it should be well insulated. The range of heat should be up to 220 degrees Fahrenheit. This oven will be used to expel the moisture from the samples. When all water is evaporated, the samples will maintain a constant weight. This is referred to as the oven-dry-weight.

Scales. Two sets of scales or balances should be available for weighing samples. One small set of balance scales should be provided that weighs up to 1,000 grams, and should be graduated in one-hundredth grams. This is used for weighing the small sections to be tested. The other set of scales should weigh up to fifty pounds and be graduated in one-hundredth pounds. This is used to weigh the sample boards. The reason for using grams and one-hundredth pounds is to make calculations more simple.

Band Saw. A band saw should be provided for sawing samples. It is used to cut sample boards and also small samples. This saw should have sufficient set to saw the lumber without creating heat which would dry the sample enough to give an inaccurate weight reading. It is also used to cut stress sections for testing for casehardening and reverse-casehardening. Shell and core samples should also be cut on a band saw.

Thermometer. A standard thermometer should be available to test the accuracy of the recorder-controller thermometers. This test should be made periodically so that a correction can be made in the controlling instrument in case that it is not accurate.

Anemometer. An anemometer should be used to test the air flow velocity in various parts of the kiln. The air flow through the kiln charge should be the same in all parts of the kiln. This test can be made by holding the instrument at various places in the kiln and taking the readings. Poor circulation may result from poor stacking, poor baffles, or a short-circuiting of the air flow.

ESTIMATED COST OF THE DRY-KILN

The proposed dry-kiln for the Oklahoma A. & M. College would not be of the most expensive or the least expensive types. The plan is to provide as much as possible for the amount of money invested. It is necessary to provide modern equipment if good drying is expected. Teaching should be done with the most efficient equipment as a teaching aid.

Building. The building will be constructed under the supervision of the Building Supervision Department of the College. Plans and specifications have been provided for this addition. The cost of the building and the loading area will be in the neighborhood of $5,000. The building is designed to accommodate one of several makes of equipment.

Equipment. The cost of the equipment should total about $2,500. This would include all of the equipment described in this Chapter. Makes or brands of equipment have not been specified in this recommendation, because there are several satisfactory manufacturers of this type kiln. The building plans have been inspected by several large companies and are satisfactory for such installations. The equipment should be installed and tested under the direction of a dry-kiln engineer.

CHAPTER VII

OPERATING A FORCED AIR COMPARTMENT TYPE DRY-KILN

This chapter will be confined to the operation of the recommended dry-kiln to be constructed at the Oklahoma A. & M. College. The plan for operating this kiln would be very similar to the operation of any other except for the size of the building and the amount of lumber that could be dried at one time.

THE BUILDING

The building has been described previously in detail in Chapter VI. The building as recommended is in keeping with the general architectural plan of the Industrial Arts Building. The present building will provide one of the walls which will reduce the cost of construction. The location is easily accessible to the Cabinet Shop.

Type of Construction. The proposed dry-kiln will be of brick and reinforced concrete construction. All footings, foundations, and building specifications have been made by a local architect who has a knowledge of the local conditions to be considered. These building specifications have been approved by several large dry-kiln equipment manufacturing companies.

Type of Drying Equipment. The drying equipment likewise has been described in Chapter VI. This equipment will operate with a minimum of heat and power and will give complete and rapid circulation of the air within the kiln. It will be under automatic control which will eliminate improper conditions that would be caused by manually operated equipment. Errors will occur only in choosing the wrong drying schedule or in setting the instruments improperly.

Lumber to be Dried. Lumber can be secured in Oklahoma to keep the kiln in constant operation. This lumber can be supplied from saw mills near Stillwater. The plan is to charge a toll for drying this lumber. The mill can provide one truck load, and at the time it is dried another load can be exchanged for the dried one. This service will be of great advantage to the college, and also to the producer.

THE KILN CHARGE

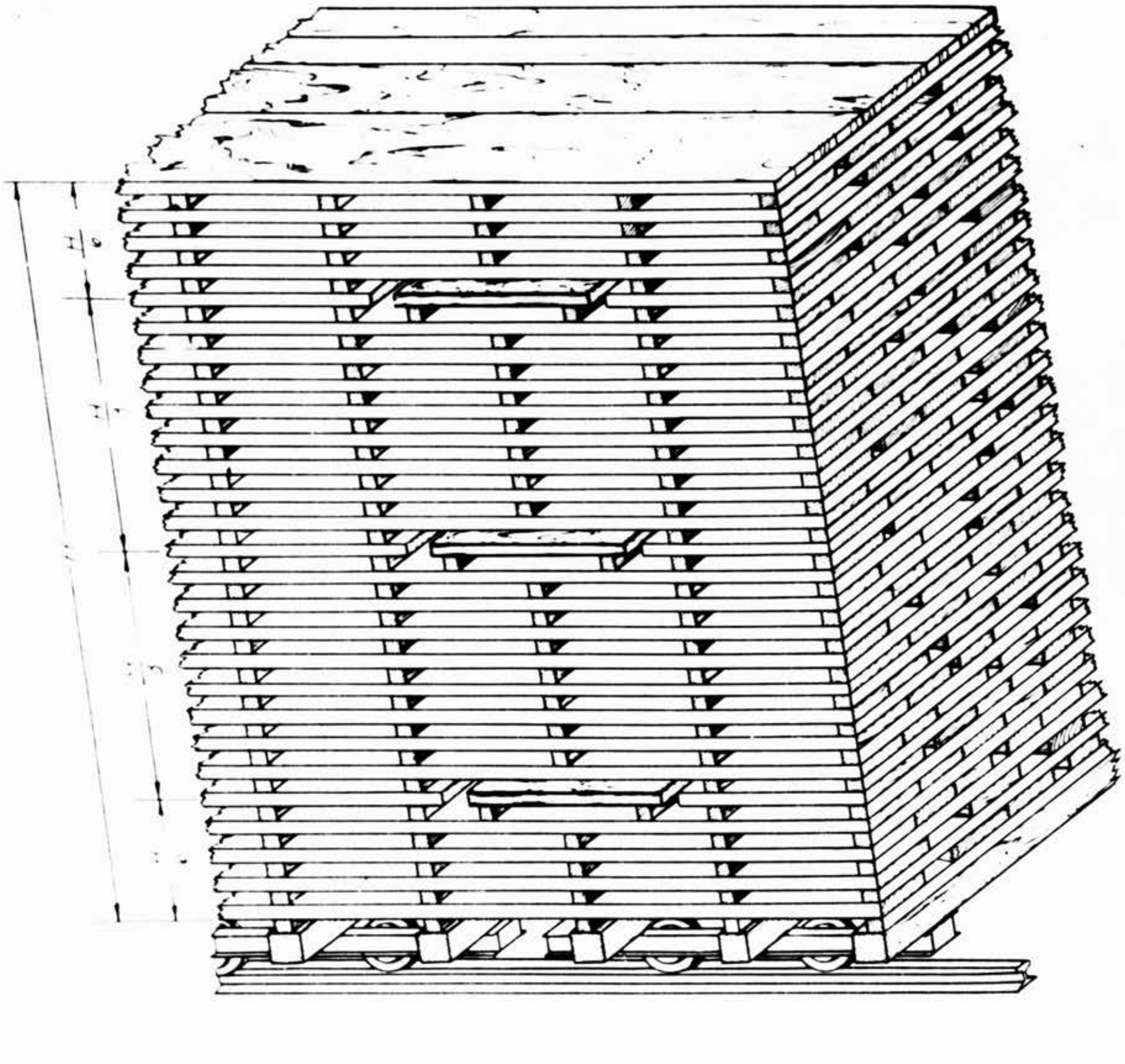
The load of lumber that would be accommodated by the dry-kiln would be an average truck load of about 5,000 or 6,000 board feet. It would be possible to have one truck load of lumber on the loading area while another one was in the kiln.

Kind of Lumber. The lumber to be dried should be all of one species and one thickness. It should all contain about the same percentage of moisture. It is not possible to choose a schedule for drying lumber which does not closely resemble these conditions. Species of lumber should not be mixed in a dry-kiln. The proposed unit will dry any charge of lumber if other conditions are met.

Condition of Lumber. The lumber should be sawed to a uniform thickness. The width of the boards is immaterial. It is much easier to handle if it is cut the same length. The lumber may be cut green from the log or may be air dried provided that it is not mixed. The lumber should be stacked properly to prevent warpage.

Piling of the Charge. The charge of lumber should be carefully piled on the kiln trucks. This can be done by placing four inch beams across the channels on two foot centers. The lumber should be stacked so that there is one support at each end of the pile. The boards should be placed edge to edge across the truck with the ends straight. Stickers made of hardwood one inch by one and one-half inch should be placed directly over the cross-beams with the end stickers at the end of the boards. Another layer of lumber is piled on these stickers the same as the first layer. This will leave a one inch air space between the layers of wood. This is continued until the lumber is all stacked. It is important to keep the stickers directly above each other, to reduce warpage.

Spaces should be provided in the lumber charge for sample boards. Figure 3 illustrates proper piling and spacing for kiln samples. These spaces should be on each side of the lumber charge with one near each end and one near the center. The spaces can be provided by cutting



Courtesy of The United States Forest Products Laboratory

Figure 3.

some of the boards into short lengths so that the spaces can be left for the sample boards. These sample boards should have stickers under them to provide proper air circulation about them. All kiln samples should be end-coated as soon as they are cut to reduce rapid end drying.

A special rack may be used to assist in keeping the lumber in alignment while piling it on the trucks. Spacer blocks may be used to arrange the stickers so that they will be directly above each other. Much time can be saved by using these devises.

The charge of lumber is placed in the kiln and a baffle is placed at each end, one from the top of the lumber to the fan deck, running the full length of the kiln, and one from the bottom of the kiln load to the floor. These baffles will cause all of the air that is circulated by the fans to pass through the charge of lumber. If baffles were not used the air would follow the path of least resistance, and the most of it would pass around the lumber at the top and bottom and at the ends.

DRYING SCHEDULE TO BE FOLLOWED

The species of lumber and the amount of moisture that it contains, together with the thickness of the boards will determine the drying schedule to be selected. A number of kiln drying schedules have been published in the United States Forest Products Laboratory, Bulletin No. 175. Table III of this report is a duplication of schedules five through eight. Several of these general hardwood schedules will be given to indicate the drying conditions to be maintained in the kiln during the drying period.

Black walnut will be selected as a material to dry and should be dried on schedule number five as indicated in the Technical Notes, Bulletin Number 175. This schedule is chosen by taking moisture sample of the kiln charge. This should be done by oven-drying because the moisture content is too high to get reliable readings from an electric moisture meter. This schedule is based on material that is one inch thick which contains forty-five percent moisture.

TABLE III

General Hardwood Schedules

Stock moisture content	Schedule 5			Schedule 6			Schedule 7			Schedule 8		
	D. B. T.	W. B. T.	R. H. %	D. B. T.	W. B. T.	R. H. %	D. B. T.	W. B. T.	R. H. %	D. B. T.	W. B. T.	R. H. %
45	120	113	80	115	108	80	110	105	85	105	101	85
40	125	116	75	120	111	75	115	108	80	110	104	80
30	130	119	70	125	114	70	120	111	75	115	107	75
25	135	121	65	130	116	65	125	112	65	120	109	70
20	140	120	55	135	116	55	130	112	55	125	110	60
15	145	119	45	140	115	45	135	110	45	130	109	50
10 to Final	150	112	30	145	108	30	140	109	35	135	107	40

D. B. T. - Dry-bulb Temperature
W. B. T. - Wet-bulb Temperature
R. H. % - Relative Humidity Percentage

Preliminary Drying Period. The preliminary drying period of about three days bring the boards above the average moisture content down to near the average so that the reaction will be similar on all pieces of lumber in the kiln charge. There will be very little drying of the drier samples.

Main Drying Conditions. The next step in drying will be to set the readings on the recorder-controller to the succeeding step that is indicated on the drying chart, and then change as the samples dry to the moisture content listed. This drying period may take a week or more depending on the amount of air circulation. The kiln samples should be weighed each day, and their moisture content recorded. This moisture content will determine the time to change the recorder-controller. Lumber should be dried as rapidly as possible without causing surface checking.

Humidifying and Sterilization. The problem of maintaining the proper amount of humidity in the kiln is solved by the use of the recorder-controller which opens the vents when the amount of humidity is too great, and opens the steam spray line when the amount of humidity is deficient. A sterilization treatment may be necessary in a dry-kiln if stain, mold or decay are developing in the lumber. In the selected schedule, it could occur only in the preliminary schedule because these conditions cannot exist when the temperature is above 120 degrees Fahrenheit. To kill the growths, the temperature should be raised to 125 degrees Fahrenheit at 100 percent relative humidity for a period of one hour for each one inch thickness of the lumber. The regular schedule should be maintained after the sterilization has taken place. The sterilization treatment should be used at any time it is needed when drying a charge of lumber.

Final Drying. The final drying period is maintained to try to get all of the samples as nearly as possible to the desired moisture content. The driest sample in the kiln should be dried to a moisture content of one percent below the moisture content of the lowest value of the final range. These conditions should be maintained until the conditioning treatment is started. The amount of time required for this stage of drying may vary from three to ten days, depending upon the species and thickness of the lumber.

Conditioning Treatment. The purpose of the conditioning treatment is to equalize the moisture content of the boards. The relative humidity will be increased to add some moisture to the outer layers of the lumber. The core of the lumber will continue to lose moisture as the shell increases in moisture content. This will equalize the stresses that occur in the lumber while it is being dried. Casehardening and reverse casehardening is relieved by this treatment. The conditioning treatment can be performed only in the compartment type dry-kilns where the conditions can be controlled.

Samples may be cut from the sample boards in the kiln charge to determine the time to remove the lumber. Two tests should be made to determine these conditions. The shell and core test will give the percentages of moisture near the surface of the boards and at the center. The test for casehardening and reverse casehardening is made by cutting the samples to indicate the tension on the prongs. If the lumber is casehardened, the prongs will close at the ends, and if it is reverse casehardened, the prongs will spread apart at the ends. The lumber must be free from these stresses if it is to be resawed. Figure 2 in Chapter II illustrates the tests that are made for these conditions.

RECORDS OF PROGRESS

A complete set of records should be kept on each charge of lumber that is being dried. There should be no guess work in drying lumber. The chance of error is too great to risk the damage that will occur in the lumber. Prepared charts are available to the operator of the dry-kiln for recording all of the conditions.

Preliminary Moisture Conditions. Enough samples should be tested while the lumber is being piled to make a reliable estimate of the moisture content. Each sample should be tested with a moisture meter if the percentage of moisture is below thirty percent. The oven-dry method of testing should be used if the moisture content is above thirty percent. The lumber can be severely damaged in the initial drying period if the improper drying schedule is used. Surface checks will occur if the drying is too rapid or if the relative humidity is too low.

Daily Readings. Final results can be more easily calculated when the readings and sampling procedures are completed at the same t ime each day. The recorder-controller chart will indicate the conditions inside of the kiln. This will give the readings of the wet-bulb temperature, the dry-bulb temperature, and the relative humidity. The sample boards should be end-coated and carefully weighed when they are placed in the kiln, and each day thereafter. These weights should be recorded on a chart, and the moisture content should be calculated. The calculations will be used as a basis for changing the drying conditions during the drying process.

When the average moisture content of the samples is one percent below the desired final moisture content the conditioning treatment should be started. The recorder-controller should then be set so that the equilibruim-moisture-content is one percent above the desired final moisture content.

Final Readings. The final readings of the kiln charge should include the moisture content of the sample boards, the moisture content of the core and the shell of the sample sections. These readings on all samples should be within a range of about two percent, if the charge is properly dried. All o f these readings are recorded on the chart.

Operations Record. A sample of the records that should be kept on a charge of lumber that is being dried in a dry-kiln will be listed. These records were made by the writer of actual drying conditions in a dry-kiln at the U. S. Forest Products Laboratory. The charge of lumber was one inch yellow birch with an initial moisture content of 34.7%. The drying schedule was taken from Technical Note No. 175, but was not followed in all respects even though the final desired results were obtained.

Record No. 1. This record is kept from day to day and shows the actual conditions within the dry-kiln. The readings of the wet-bulb and dry-bulb temperatures are obtained from the recorder-controller chart. The other calculations are made from these figures. It has been found to be more convenient to make the calculations if the instruments are read at the same time each day.

Record No. 2. This record is a daily reading of the new weight of the kiln sample. This weight is used in calculating the moisture content. Conditions of the dry-kiln are changed to conform to the selected schedule using the moisture content as the basis for the necessary revisions.

Record No. 3. This record merely indicates the moisture distribution of the kiln sample when the drying has been completed. There should be a very slight difference between the moisture content of the shell and the core of the sample. The method of cutting this moisture distribution sample is shown in Figure 2, page 27, of this report.

TABLE IV

One Inch Yellow Birch
(Technical Note No. 175)

Moisture content at which changes should be made	Dry-bulb Temp.	Wet-bulb Temp.	Relative Humidity
Percent	Degrees F.	Degrees F.	Percent
40 or more	140	132	80
30 to 40	145	135	75
25 to 30	150	137	70
20 to 25	155	136	60
15 to 20	160	135	50
10 to 15	165	127	35
10 to final	170	116	20

RECORD NO. 1

Record of Kiln Conditions

Species, Yellow Birch				Started 9-16-48		Finished 9-28-48
Date	Hour P. M.	Dry-bulb	Wet-bulb	Wet-bulb depres.	R. H.	E. M. C.
		°F.	°F.	°F.	Percent	Percent
9-16	2	140	132	8	80	13.0
9-20	2	142	134	8	80	13.0
9-20	2	160	135	25	50	6.8 Cond. Ch.
9-21	2	160	136	24	52	7.0
9-21	2	165	127	38	34	4.6 Cond. Ch.
9-22	2	165	126	39	33	4.4
9-23	2	165	127	38	35	4.6
9-23	2	170	135	35	39	5.0 Cond. Ch.
9-24	2	170	135	35	39	5.0
9-25	2	170	135	35	39	5.0
9-27	2	170	135	35	39	5.0
9-27	2	170	154	16	67	9.0 Cond. Ch.
9-28	2	24 hours conditioning at 9% E. M. C.				

RECORD NO. 2

Record of Kiln Sample

Species, Yellow Birch				Started 9-16-48			Finished 9-28-48		
Date	9-16	9-20	9-21	9-22	9-23	9-24	9-25	9-27	9-28
Hour, P.M.	2	2	2	2	2 #	2	2	2	2
T. Hours	0	96	120	144	168 #	192	216	268	292
Weight	3351	2890	2774	2692	2652 #	2144	2135	2121	2141
M. C.	34.7	16.2	11.5	8.2	6.8 #	7.5	6.4	5.7	6.7

Intermediate section was cut which gave a new weight.

RECORD NO. 3

Moisture and Stress Record After Conditioning

Shell			Core			Average		
Wt. Grs.	O. D. Wt. Grs.	M. C. %	Wt. Grs.	O. D. Wt. Grs.	M. C. %	Wt. Grs.	O. D. Wt. Grs.	M. C. %
47.19	44.00	7.3	30.22	28.22	7.1	73.21	68.46	7.0

Conclusions. All records that are made on a charge of lumber should be evaluated and filed for future reference. When loads of lumber having similar conditions are dried, the records may be used as a guide to more efficient operation. The time spent on keeping complete records is well worth the effort. All recorder-controller discs should be labeled and filed for future comparisons.

The use of these records may mean a saving of one or more days time in drying a charge of lumber which in turn reduces the drying costs.

Lumber can be dried to complete satisfaction if the above outline is followed. These directions will apply to the operation of any Forced-air Compartment Type Dry-Kiln. The size of the kiln, and the kind of equipment will of course alter some of the conditions, but an experienced operator will be able to meet the demands. The larger kilns will require more time for checking and maintaining proper conditions than the smaller ones.

A SELECTED BIBLIOGRAPHY

1. Henderson, Hiram L., The Air Seasoning and Kiln Drying of Wood, Albany, New York, 1946, 332 pages.

2. Henderson, Hiram L., Henderson Dry Kilns, Syracuse, New York, 1922, 63 pages.

3. Hunt, DeWitt, A Manual for Hand Woodworking, Harlow Publishing Co., Oklahoma City, Oklahoma, 1925, 165 pages.

APPENDIX I

The following is a list of Technical Notes and Reports that have been prepared and published by the U. S. Forest Products Laboratory. These publications have been studied in the preparation of this report, and should be accessible to all dry-kiln engineers. Other books used in the preparation of this report are listed in the foregoing bibliography.

Technical Notes

B-11	Method of determining the moisture content in wood.
D-5	Correct moisture content of lumber.
F-13	Moisture content of wood at different humidities.
124	Materials used in dry-kiln construction.
148	Care and use of the hygrometer in kiln drying.
156	Humidity table for wet and dry bulb hygrometer.
175	Hardwood and softwood drying schedule.
180	Comparative strength of air-dried and kiln-dried wood.
186	Coatings that prevent end checks.
208	Reversible circulation internal fan kilns.
213	Detection and relief of casehardening.
218	Weights of various woods grown in the United States.
233	Approximate air seasoning and kiln drying periods for inch lumber.
234	Longitudinal shrinkage of wood.
241	Shrinkage table for softwood lumber.

Technical Notes (Cont'd)

252 Fiber-saturation point of wood.

United States Forest Products Laboratory Processed Reports

R859 "The Fiber-Saturation Point of Wood as Obtained from Electrical Conductivity Measurements", by A. J. Stamm, 1929.

R958 "Dimension Changes in Millwork Due to Varying Atmospheric Conditions", by J. S. Mathewson, Wood Working Industry, June, 1930.

R958 "Proper Care of Millwork", The Constructor, November, 1930.

R1023 "An Electrical Conductivity Method for Determining the Moisture Content of Wood", by A. J. Stamm, Industrial and Engineering Chemistry, July, 15, 1930.

R1093 "Longitudinal Shrinkage of Wood", by Arthur Koehler, American Society of Mechanical Engineers, Transactions, Wood Industries, April, 1931.

R1140 "Controlling Moisture Changes in Lumber in Closed Storage Sheds", by J. S. Mathewson, Timberman, February, 1937.

R1140 "Automatically Controlling Lumber Storage Conditions", Canada Woodworker & Furniture Manufacturer, March, 1937.

R1174 "Seasoning of Beech Lumber and Dimension Stock", by R. C. Rietz, 1938.

R1205 "Ventilation in a Dry-Kiln", by W. K. Loughborough, South. Lbrman., Oct. 15, 1940; Wood Products, Dec. 1931; Wood Working Indus., July 1931.

R1242 "Seasoning Dimension Stock", by O. W. Torgeson, Wood Working Indus., June 1932; Furn. Index, Oct. 1932.

R1263 "Techniques of Developing a Drying Process for Small Stock", by O. W. Torgeson, 1940.

R1267 "Uniformity of Air Distribution in a Lumber Dry-Kiln", by O. W. Torgeson, <u>South. Lbrman</u>, April 15, 1940.

R1269 "Why the Drying Time of a Kiln Load of Lumber is Affected by Air Velocity", by O. W. Torgeson, 1941.

R1433 "Kiln Schedules for Black Walnut Gunstock Blanks", by H. H. Smith and O. W. Torgeson, 1943.

R1448 "Effect of Moisture Changes on the Shrinking, Swelling, Specific Gravity, Air Space, Weight, Similar Properties of Wood" by J. D. MacLean, 1944.

R1474 "Furnace-type Lumber Dry-Kiln", by O. W. Torgeson, 1945.

R1474-A "Furnace-type Lumber Dry-Kiln", Supplement to R1474, "Operation of an Experimental Unit", by H. H. Smith, 1945.

R1478 "Steam Reuirements in Lumber Dry-Kilns", by L. V. Teesdale, 1936.

R1602 "A Wood-element Hygrostat", by S. J. Johnson and E. F. Rasmussen, 1946.

R.607 "Use of Kiln Samples in Operating a Lumber Dry-Kiln", by H. H. Smith, 1946.

R1642 "How Wood Dries", by W. J. Baker, Eebruary 1947.

R1644 "Kiln Tune-ups to Correct Nonuniform Kiln-Drying Conditions", by E. F. Rasmussen, March, 1947.

R1645 "Analysis of Problems Relating to Uniformity of Kiln Control", by E. F. Rasmussen, March 1947.

R1646 "Dry-kiln Building Materials and Construction", by L. V. Teesdale, March 1947.

R1647 "Economical and Efficient Kiln Operation", by W. K. Loughborough, April 1947.

R1648 "Some Wood-moisture Relations", by L. D. Espenas, April 1947.

R1649 "Methods of Determining the Moisture Content of Wood", by J. M. McMillen, April 1947.

R1650 "Shrinkage of Wood", by E. C. Peck, May 1947.

R1652 "Drying Stresses in Lumber Seasoning", by W. J. Baker, July 1947.

R1653 "Effect of Piling Methods on Air Circulation in a Lumber Dry-Kiln", by O. W. Torgeson, July 1947.

R1654 "Temperature Measuring and Controlling Devices in Lumber Dry-Kilns", by K. E. Kimball, Sept. 1947.

R1659 "Construction and Use of Graphs in Kiln Drying Lumber", by K. E. Kimball, August 1947.

R1660 "Electrical Moisture Meters for Wood", by E. R. Bell and M. E. Dunlap, November 147. Supersedes Report R1146 of the same title.

R1661 "Types of Lumber Dry-Kilns", by E. F. Rasmussen, March 1947.

R1663 "Types of Steam-Heating Systems, Flow of Steam, Cause and Effect of Air and Water Binding, Importance of Steam Traps, Steam Pressure, and Heat Transfer in Lumber Dry-Kilns", by E. F. Rasmussen, March 1947.

R1664 "Steam Traps", by K. E. Kimball, January 1947.

R1669 "Need for Uniformity of Temperature in a Dry-Kiln", by W. K. Loughborough, May 1947.

R1673 "Steaming Black Walnut Lumber to Darken the Sapwood", April 1947.

R1678 "Circulation of Air in a Lumber Dry-Kiln", by O. W. Torgeson, July 1947.

R1685 "Method for Controlling the Moisture Content of Wood Going into Furniture Production", by R. C. Rietz, September 1947.

R1702 "Kiln Drying of White Birch Turning Squares", by H. H. Smith, December 1947.

1363 "Shrinkage of Wood", 1941.

1369 "Kiln-Drying Effects", 1941.

APPENDIX II

FIRMS IN THE UNITED STATES THAT MANUFACTURE AND DISTRIBUTE DRY-KILN EQUIPMENT

Drying Systems, Inc.
1800 Foster Avenue
Chicago 40, Illinois

Perfection Dry-Kiln Co.
121 West 4th Street
Jamestown, New York

Grand Rapids Vapor Kiln, Inc.
Grand Rapids, Michigan

C. M. Lovsted & Co., Inc.
2214 First Avenue So.
Seattle 4, Washington

Imrie Dry Kiln Co.
Grand Rapids, Mich.

Dry Kiln Door Carrier Co.
Indianapolis, Indiana

Industrial Air Co.
20 Chestnut St.
Needham, Massachusetts

Robert W. Resser
Dry Kiln Engineer & Consultant
P. O. Box 91
Little Rock, Arkansas

B. F. Sturdevant Co.
Hyde Park
Boston, Mass.

Standard Dry Kiln Co.
798 South Harding St.
Indianapolis, Ind.

Herbert Fryer
Carnation, Washington

Hiram L. Henderson
119 Stoneridge Drive
Syracuse, New York

Kiln Supply & Mfg. Co.
5825 Oak Avenue
Indianapolis 1, Ind.

Moore Dry Kiln Co.
Jacksonville, Florida

The National Engineering Co.
P. O. Box 1475
Indianapolis 6, Ind.

The New York State College
of Forestry
Syracuse University
Syracuse, New York

Redman Engineering Service
High Point, N. C.

Taylor Instrument Co.
P. O. Box 110
Rochester 1, New York

Typist: Willnetta Horner