

DRY KILN BUILDING MATERIALS AND CONSTRUCTION

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FOREST PRODUCTS LABORATORY
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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

In Cooperation with the University of Wisconsin

DRY KILN BUILDING MATERIALS AND CONSTRUCTION¹

By

Forest Products Laboratory,² Forest Service
U.S. Department of Agriculture

Introduction

The purpose of this report is to describe and discuss various materials and constructions used to build lumber dry kilns. While dry-kiln manufacturers generally supply plans and specifications for kilns for which they furnish the equipment, the kiln owner may often desire to use materials and constructions adapted to the conditions peculiar to his locality or business operation, such as availability of materials, construction costs, and permanent or temporary need for a kiln, kinds of lumber to be dried, and operating conditions. This report presents information intended to aid him in making an intelligent choice among the various materials and construction methods available. For more detailed guidance, the builder can consult dry-kiln companies or engineers who specialize in dry-kiln construction.

Service Life of Kilns

Kiln structures are made of masonry, wood, or fabricated panels of various materials. Regardless of the material used, kiln structures deteriorate more rapidly than ordinary buildings. All structures are subject to normal deterioration from exposure to weather, but dry kilns are also exposed to accelerated deterioration from several other sources.

Kilns go through wide and frequent temperature variations that cause expansion and contraction in the materials used in construction. Dimensional changes damage some materials more than others. Solid concrete walls may develop a few large cracks, concrete block walls several smaller cracks, brick walls may have numerous very small and perhaps almost invisible cracks.

¹Original report written in March 1947 by L. V. Teesdale, former Forest Products Laboratory engineer.

²Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

If kiln-drying conditions could be maintained at fixed temperatures, dimensional changes would cause little deterioration. Good kiln operation, however, calls for variations in temperature, and normal kiln operation means occasional shut-down for various reasons. The so-called daytime method of kiln operation means daily temperature changes of considerable magnitude. Kilns in cold climates go through wider temperature changes than those in mild climates. Kiln schedules for fast-drying softwoods may mean a cycle of low to high temperature, repeated every 3 days, while some of the cycles for slow-drying hardwoods may not be completed in a month. Thermal expansion and contraction are to a large extent proportional to the sizes of the units involved, so temperature changes would affect a concrete block more than a brick and a long wall more than a short one.

High vapor pressure in kilns also causes damage and deteriorates the structure. Wood, brick, tile, concrete blocks, and concrete are permeable to water vapor. Condensation in outside walls hastens deterioration that may have started from expansion. Condensation can cause decay in wood roofs and rusting of reinforcement in concrete roofs, and is objectionable in other types of roofs.

Some species of wood give off vapors that corrode metals and may combine with condensation to deteriorate masonry.

Good engineering practices and protective measures not required in ordinary construction can minimize the damaging effects of temperature changes, moisture, and corrosive vapors.

Factors to be Considered in Building a Dry Kiln

High maintenance costs and relatively short overall life of the building can be expected when construction costs are held to a minimum by use of inferior materials and building methods. Cutting first cost may be justified for a setup where the operation is to be short-lived. Where the kilns are to be part of a permanent operation, however, construction materials that result in low maintenance costs, extended life, low fuel costs, low insurance rates, and close control of drying conditions should be considered. Proper materials and the best engineering practices may increase the initial cost, but this will be more than offset by reduced operating and maintenance costs and better control of drying conditions.

This report discusses some of the properties of various building materials and the relative suitability of these materials for dry-kiln construction. It is the function of the dry kiln manufacturers or engineers to specify the materials and design requirements for a particular kiln setup.

Building Materials

Wood, concrete, brick, terra-cotta tile, asbestos-cement board, and metal are materials most commonly used to build kilns. Combinations of these materials are also used; for example, wood framing covered with asbestos-cement board. New materials are constantly being developed to reduce thermal expansion and contraction and heat and vapor losses and to increase resistance to corrosion and fire.

Tables 1 and 2 list values for the coefficient of heat transmission of a number of structural combinations that may be used in kiln walls and roofs. Similar values can be obtained from manufacturers of other building materials or from dry-kiln manufacturers and engineers. Information on other properties of these materials, such as their coefficient of thermal expansion and resistance to vapor movement, corrosion, and fire, can also be obtained from manufacturers or from handbooks.

Where local building codes or insurance requirements permit it, wood may be used for all construction above grade. Wood has certain advantages, such as good resistance to heat transmission, ease of repair, and low first cost. It is, however, inflammable, subject to decay, and undergoes dimensional changes associated with changes in its moisture content. Wood kilns are generally shorter-lived than masonry kilns. Maintenance costs, particularly in cheaply built structures, are high. Most dry-kiln manufacturers and engineers do not favor the use of wood in kiln construction.

Concrete, concrete blocks, and brick are fireproof and will not decay. They do, however, expand and contract -- a characteristic that hastens their deterioration. These materials are difficult to repair, low in resistance to heat flow, and expensive. Solid concrete and concrete blocks make strong walls, but they are subject to concentrated expansion cracks. Hard-burned brick makes excellent but expensive walls.

Wood or metal frames covered with asbestos-cement or aluminum sheets are sometimes used. Insulation and vapor barriers are added when needed to reduce heat and vapor transmission.

Fabricated panels of wood or metal are being used increasingly in the construction of prefabricated kilns. At present, the cost of such structures is higher than that of masonry structures. Improved and faster methods of fabricating such panels, however, are resulting in lowered first costs. Other advantages of certain types of panel construction, such as reduced heat and vapor losses, ease of erection, ease of disassembly and moving, greater resale value, lower maintenance costs, and longer life, may result in savings that will more than compensate for the higher initial costs.

Structural Details

Foundations

Kilns must be built on firm foundations, because foundation settlement causes structural misalignment and formation of settlement cracks, which are more serious in kilns than in many other types of construction. Misalignment throws the trackage system out of line and creates difficulties in the movement of kiln trucks. Cracks cause loss of heat and make humidity control difficult. When kilns must be built on insecure soil, a competent architect or engineer familiar with local conditions should be consulted.

Kiln foundations are almost invariably made of concrete. Their width or bearing area is determined by the character of the soil and by the loads to be imposed upon them. Foundation walls are usually about 10 inches thick where wood walls are used above grade. Kiln walls of masonry have the same thickness as the foundation walls. Concrete footings and foundations should be waterproofed if they are likely to be in contact with ground water.

Floors

Most kilns are provided with concrete floors, usually 4 inches thick. Natural soil floors are not recommended, particularly in forced-circulation kilns.

Walls

Kiln walls must be strong enough to support, besides the roof, any overhead fans, motors, shafts, and heating systems suspended from them. All exterior walls, and in some cases those walls between adjacent kilns in a battery of two or more kilns, should be well insulated. All walls should be resistant to vapor transmission. Heat and vapor transmission through walls separating adjacent kilns may upset drying conditions.

Wood walls.--Standard wood walls (fig. 1) are constructed of 2- by 6-inch studs 16 inches on center covered with 1-inch sheathing inside and with sheathing and bevel or drop siding outside. Sheathing is usually shiplap or matched lumber laid horizontally. All sheathing exposed to kiln conditions should be nailed with two nails to each stud, one at the center and one at the bottom of each board, so that slight shrinkage and swelling can take place.

To prevent moisture vapor from passing from the kiln into the outside face of the wall, a vapor barrier should be placed in the inside face of the wall. A suitable material is roll roofing applied vertically over the face of the studs before the inner sheathing is applied. Joints should be well sealed. If any sheathing paper is used between the siding and sheathing in the outside face of the wall, it should be a waterproof but not vaporproof material, such as tarpaper or slater's felt.

Crib or laminated walls (fig. 1), consisting generally of 2- by 6-inch stock laid flat one on top of another and well nailed, are sometimes used where lumber is plentiful and cheap. Such a wall is termed "slow-burning," and it often has a lower insurance rate than a standard frame wall. Vapor loss through the joints may be excessive and interfere with maintenance of kiln schedules. Vapor loss can be reduced by installing a vapor barrier on the inner face. This barrier may be protected from damage by wood strips or sheathing nailed over it.

Concrete walls.--Poured concrete is seldom used for walls above grade because of its cost, low insulating value, large expansion cracks, and low resistance to vapor transmission. In some cases, however, it is the most available material. Concrete partition walls should be at least 8 inches thick and outside walls not less than 12 inches thick. Concrete pilasters at intervals of 16 to 20 feet will increase stiffness materially. A 1/2-inch expansion joint should be provided in each 40 feet of wall length. The joint should be vertical and can be of the tongue-and-groove type.

Concrete block walls.--Most dry kiln manufacturers are opposed to use of concrete blocks made of sand and gravel or crushed stone aggregate, but blocks made of so-called lightweight aggregates, such as expanded blast-furnace slag, hard-burned cinders, or perlite, are widely used. These lightweight aggregates have much better insulating properties and are less affected by expansion than are gravel and stone aggregates. Concrete blocks should be laid in tempered cement mortar. Some kiln manufacturers recommend that three 1/2-inch reinforcing rods be laid horizontally in long exterior walls to help restrain expansion. These rods are laid in the mortar joint as the wall is erected, one about three blocks above the grade, one at midheight, and one near the roof.

Concrete block walls may, of course, be faced with brick veneer to improve appearance.

Brick walls.--Brick walls should be made of dense, hard-burned brick laid in tempered cement mortar. No soft or salmon brick should be used, as these are likely to disintegrate. The walls should be 13 inches thick and strengthened with pilasters not more than 20 feet apart.

Terra-cotta tile.--Terra-cotta tile should be of the dense, load-bearing type, hard-burned, and laid in tempered cement mortar. Sometimes exterior tile walls are faced with brick or stuccoed. Walls should be 12 inches thick and reinforced with pilasters not more than 20 feet apart.

Panel walls.--Panels for most prefabricated kilns are made by the kiln manufacturer. Erection instructions should be followed closely. Gaskets should be installed, or sealers applied at the junction between panels, when required to reduce heat and vapor losses.

Kiln paint.--Most building materials, particularly masonry and wood, are permeable to vapor. Excessive vapor leakage through walls can seriously affect humidity control and add to rapid deterioration, particularly in exterior walls. Suitable paints or plastic coatings overcome or reduce these disadvantages. It is good practice to apply a 15-pound impregnated asphalt felt over the inside coating of exterior concrete block walls. The exterior face of concrete walls should be treated with a water repellent to shed storm water. Do not use a vapor-resistant coating.

The dividing walls in masonry or wood kilns should also be coated to prevent vapor leakage between kilns. All exposed piping and structural steel should be painted with a suitable boiler or stack paint. Coatings especially prepared for this class of service and exposure may be obtained from the following concerns:

Black Cat Corp.
Hattiesburg, Miss.

A. C. Horn Co.
43-46 Tenth St.
Long Island City 1, N. Y.

Moore Dry Kiln Co.
Jacksonville, Fla., or
North Portland, Oreg.

Ohmlac Paint & Refining Co.
6550 S. Central Ave.
Chicago 38, Ill.

Tropical Paint Co.
Cleveland, Ohio

Other paint companies or dry kiln companies and engineers may also supply special coatings for dry kilns.

Roof and Ceiling

A good roof must be structurally sound, weatherproof, durable, resistant to heat loss, nearly flat on the underside, but with sufficient pitch on the top to drain properly, and it must be fireproof where building codes or insurance rules require.

Occasionally, it is advantageous to separate the roof from the ceiling by a space or attic (fig. 2, top). In this case, insulation can be used over the ceiling, and the attic space can be ventilated to remove any moisture that passes through the ceiling. Such double construction is generally of wood.

Flat roofs are generally covered with a composition or a tar-and-gravel roof (fig. 2, bottom). Properly built, flat roofs give satisfactory service with a pitch of as little as 1/8 inch per foot.

Wood roofs.--Wood roofs should be limited to kilns in which low humidity schedules will be used, such as those for thoroughly air-dried stock. High

humidity schedules will cause condensation to collect under the roof covering and within the roof deck and set up conditions favorable for decay. A wood roof may last from 3 to 10 years, depending upon conditions.

Crib or laminated roof construction is sometimes used where a "slow-burning" type of construction is desired. This roof is generally made of 2- by 8-inch planks laid on edge and spiked firmly together to span the width of the kiln.

Wood joists, spaced 16 to 24 inches on centers and of a size suitable for the span are more commonly used in wood roofs (fig. 2, bottom). At least one row of bridging should be provided. It pays, in added life and in maximum insulating value, to give considerable thought to the method of applying the roof sheathing. A layer of nominal 1-inch roof sheathing has low resistance to heat loss, and condensation collects on its under surface and drips back on the lumber. Such roofs are likely to decay in a short time. With 2-inch sheathing, the heat loss is reduced, and less condensation develops, but moisture may collect in the sheathing below the roofing and set up conditions favorable for decay. A roof with good insulating properties and longer life can be made by placing a layer of 1-inch lumber on top of the joists, covering it with a vapor barrier of roll or composition roofing that is mopped down with asphalt, covering this with 2-inch sheathing, two thickness of 3/4-inch fiberboard, or other suitable insulation, and finally covering the whole with composition roofing.

Because of the decay hazard, it is generally undesirable to use matched ceiling on the underside of the roof joists unless provision is made for adequate ventilation of the space between ceiling and roof. If this type of construction is followed, a vapor barrier should be provided at the ceiling and insulation should be placed above the ceiling between the joists. The double roof (fig. 2, top) is, however, a more satisfactory method of construction where a level ceiling is desired.

The service life of the roof sheathing can be materially lengthened by using lumber that has been pressure treated with preservatives. Untreated wood of high durability, such as the heartwood of redwood and western redcedar, may be expected to give longer service than that of less durable species.

Reinforced-concrete roof.--Slab roofs of reinforced concrete are occasionally used (fig. 3). Since the heat loss through concrete is high, such roofs should be adequately insulated. A vapor barrier consisting of three plies of roofers' felt mopped down on top of the slab can be covered with any suitable insulation, such as 2 or 3 inches of cork board or three or more thicknesses of 3/4-inch fiberboard. Suitable expansion joints should be provided over the bearing walls and elsewhere, as described for concrete walls.

Concrete slabs are generally supported by steel beams that are spaced about 6 feet apart and span the kiln chamber. One manufacturer has used a 3-inch slab made of expanded slag aggregate reinforced with mesh and supported on

steel beams spaced about 4 feet apart. Others have used corrugated asbestos-cement board supported by steel beams about 4 feet apart and covered with concrete made of vermiculite aggregate. Precast concrete slabs with hollow cores have also been used.

None of the types of roofs described have been wholly satisfactory, but they do have most of the properties desired. Some do not lend themselves to the application of a vapor barrier, and condensation may collect on them.

Improved roof construction.--Moisture in kiln roofs creates conditions that favor rapid deterioration. Water vapor from the kiln passes through the material on the warm side and condenses at or near the underside of the outer roof covering. This moisture creates a decay hazard in wood roofs, rusting and ultimate failure of reinforcing steel, damage to vermiculite concrete, and loss of insulating value if moisture collects in the insulation.

Kiln coatings retard vapor transfer, but they do not stop it. Some leakage also takes place through vapor barriers. Roof construction can be designed to protect dry kiln roofs from the effects of condensation. In principle, the roof would be in two parts. The ceiling section would consist of structural supports, a ceiling covering, a vapor barrier, and the insulation. The roof section would be separated from the ceiling section by at least a 1-foot air space to allow the circulation of outside air over the ceiling section.

The ceiling section may be any wood or concrete roof type described but without the composition roof covering. This allows moisture to work up through the barrier, escape into the air space, and be carried away by ventilation.

The roof section may be corrugated sheet metal, cement-asbestos board, or any other suitable material supported on a light framework resting on the ceiling section. All kiln vents should be carried above the roof section.

Vapor Barriers

Only a limited number of the materials used as vapor barriers in house construction are suitable for use under exposure to the high temperatures found in a kiln roof. Coatings used on kiln walls are vapor resistive and materially retard the amount of vapor that passes through an exterior wall. The small amount of vapor that works through these coats will escape outward without causing too much damage to the wall. The temperatures and humidity in a kiln will deteriorate these coating materials in time, therefore, the walls should be recoated about once a year.

Composition roofing has high vapor resistance, but as a vapor barrier it is in the wrong position. Wood, concrete, and most other materials used for the roof deck are permeable to vapor. Water vapor from the kiln can work through such materials to the underside of the roofing, where it may condense. The proper position for a vapor barrier is on the warm side of the roof deck.

The membrane types of vapor barriers suited for use in dry kilns would include (1) asphalt-impregnated and coated felts, such as roll roofing, made with a high-melting point asphalt, (2) polyethylene membrane in a 6-mil thickness, and (3) electrolytic copper, of 2-ounce weight, mounted on reinforced paper backing.

Doors

It is difficult to make a door that is strong, lightweight, easy to handle, resistant to corrosive action, and yet has high insulating properties. Some dry-kiln manufacturers have developed special composition doors that have most of the desired properties. They can also furnish plans and assembly details for lightweight, built-up wood doors that have proved fairly satisfactory when constructed by a skillful carpenter.

Most kiln doors are hung on rollers that operate on a rail over the door opening. Hinged doors are sometimes used, but they have not generally proved satisfactory.

Small inspection doors should be provided in each kiln to allow the operator to inspect the lumber during the drying operation. Such doors can be cut into the main door if no other space is available. Door latches should be operable from the inside as well as the outside of the kiln.

Heat Transfer

Heat conductivity or heat transmission is usually expressed as the amount of heat in British thermal units (B.t.u.) that will pass in 1 hour through 1 square foot of a given material of stated thickness. Where a combination of materials is involved, as in a complete wall, a value called the coefficient of transmission, or "U" value, is obtained. The U value can be calculated for any combination of wall or roof materials and the relative resistance to heat transmission can be compared to that of other combinations of materials. Tables 1 and 2 give the U value for a number of combinations of materials used in walls and roofs of dry kilns. The U value represents the loss of heat in B.t.u.'s per hour per square foot per degree of difference in temperature on opposite sides of the unit or wall or roof. The lower the U value, the lower is the heat loss.

Kilns made of materials with high U values will have high heat losses; temperatures and humidities within the kiln are likely to vary; drying conditions will not be uniform; and drying times may be extended. Kilns made of material with low U values will use less steam; their boiler load will be reduced; their drying conditions will be more uniform; and drying time will be shortened.

Walls and roofs of wood construction are readily insulated. Walls of masonry construction require furring strips for attachment of insulation. Vapor barriers should be installed in all walls and roofs where insulation is used. Vapor barriers can be vertically mounted on walls by tacking them to the studs or furring strips and can be covered with matched sheathing or asbestos-cement board. The seams in the barriers should be sealed.

Lightweight aggregates used in concrete blocks include (1) expanded slag, (2) burned clay, and (3) clean cinders. These aggregates are also used in concrete roof slabs. Vermiculite, is also used as an aggregate in some types of concrete. Because vermiculite does not have the crushing strength of the other types of aggregates, its use is generally limited to places where strength is not required.

Prefabricated Kilns

Some dry kiln manufacturers have developed standard wall and roof panels, doors, ducts, and other modular units necessary for a complete kiln. These may be erected indoors or outdoors.

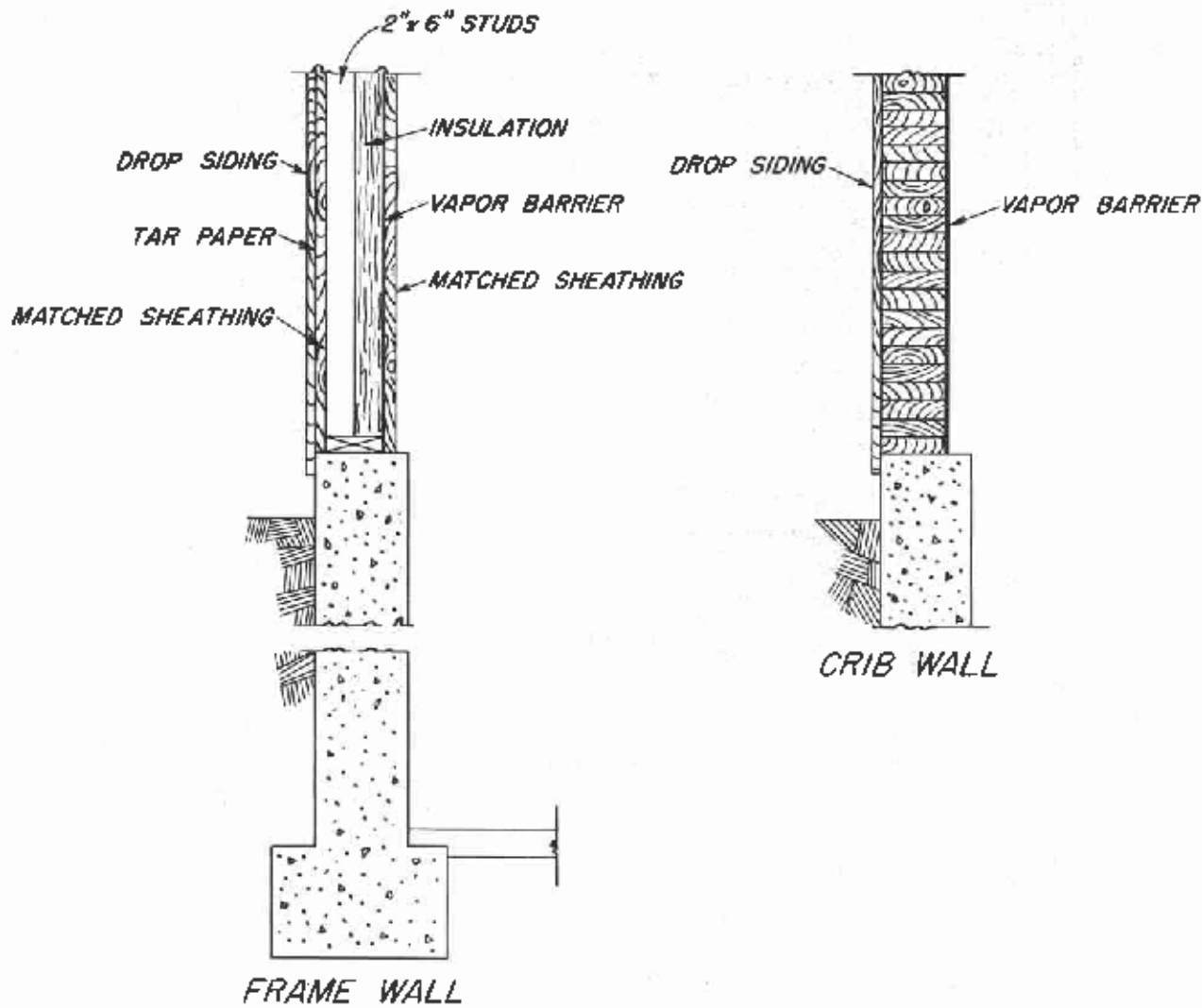
The panels, which are generally made of sheet aluminum, should be well insulated, and all joints should be sealed to prevent entry of moisture. Prefabricated kilns, when properly designed and manufactured, should give good service. Many of the problems common to wood and masonry kilns may not occur, but it would be presumptive to assume that such kilns would be free from maintenance problems.

Table 1. -- Coefficient of heat transmission for a number of structural combinations of dry kiln walls

Outside covering	Sheathing material	Insulation	Inside covering	Coefficient of transmission
WOOD FRAME WALLS				
Bev. siding	:25/32 shiplap	:None	:25/32 shiplap	: 0.245
Do.	do.	:2-inch blanket	do.	: .087
Do.	do.	:3-5/8-inch blanket	do.	: .057
Do.	:3/4-inch fiberboard	:None	do.	: .191
Do.	do.	:2-inch blanket	do.	: .080
Do.	do.	:3-5/8-inch blanket	do.	: .054
Do.	:25/32 shiplap	:None	:3/8-inch cement and asbestos board	: .320
Do.	do.	:2-inch blanket	do.	: .095
Do.	do.	:3-5/8-inch blanket	do.	: .061
CRIB WALLS				
Crib or laminated wall,	6 inches thick, no covering			.125
Crib or laminated wall,	6 inches thick, outside covered with drop siding			.114
MASONRY WALLS				
Monolithic concrete wall,	8 inches thick			.700
Monolithic concrete wall,	12 inches thick			.570
Concrete block,	12 inches thick, gravel or crushed stone aggregate			.490
Concrete block,	12 inches thick, cinder aggregate			.380
Concrete block,	12 inches thick, slag or burned-clay aggregate			.340
Brick wall,	13 inches thick			.360

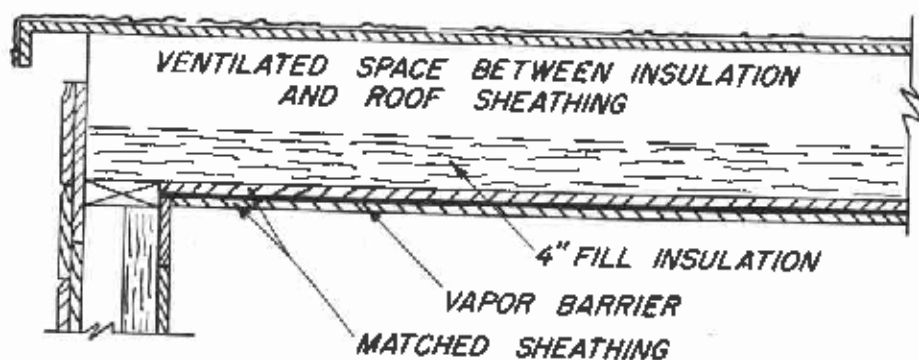
Table 2. -- Coefficient of heat transmission for a number of structural combinations of dry kiln roofs

Structural combination	Coefficient of transmission
Roof sheathing, 25/32-inch and composition roofing	0.602
Roof sheathing, 1-5/8-inch and composition roofing	.380
Roof sheathing, 25/32-inch, vapor barrier, 1-5/8-inch sheathing, and composition roofing	.278
Roof sheathing, 25/32-inch, vapor barrier, 2 layers of 3/4-inch fiberboard	.173
Ceiling, 25/32-inch, 2-inch blanket insulation, ventilated attic under roof	.108
Ceiling, 25/32-inch, 3-5/8-inch blanket insulation, ventilated attic under roof	.065
Laminated or crib roof, 6 inches thick, and composition roof	.125
Laminated or crib roof, 8 inches thick, and composition roof	.096
Concrete slab, gravel aggregate 4 inches thick, and composition roof	1.010
Concrete slab, gravel aggregate 4 inches thick, 2 layers of 3/4-inch fiberboard or 1-1/2-inch cork composition roof	.195
Concrete slab, 3 inches thick, expanded slag aggregate, and composition roof	.530
Concrete slab, 6 inches thick, expanded slag aggregate, and composition roof	.326
Corrugated asbestos-cement board, vapor barrier, 5 inches vermiculite concrete (1 to 6 mixture), composition roofing	.159

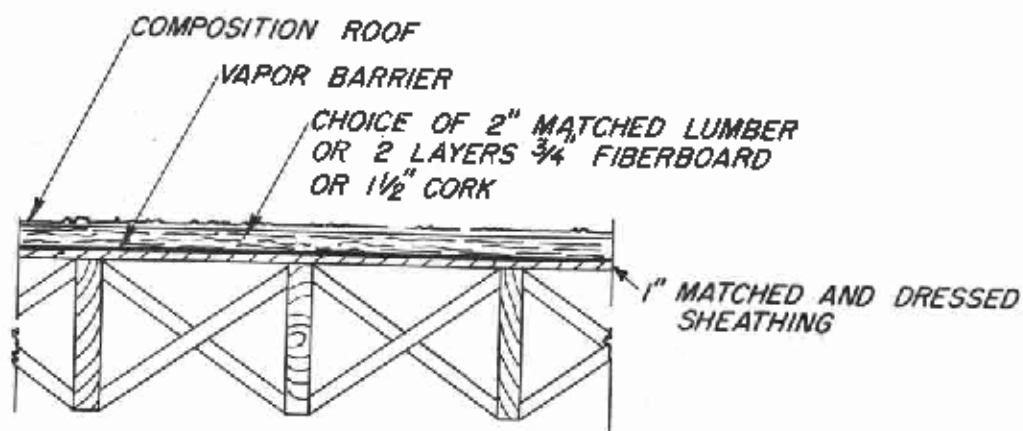


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Figure 1.--Wood wall types.



WOOD JOIST WITH CEILING BELOW



STANDARD JOIST CONSTRUCTION

Figure 2.--Roof types: wood joist with ceiling below; and standard joist construction.

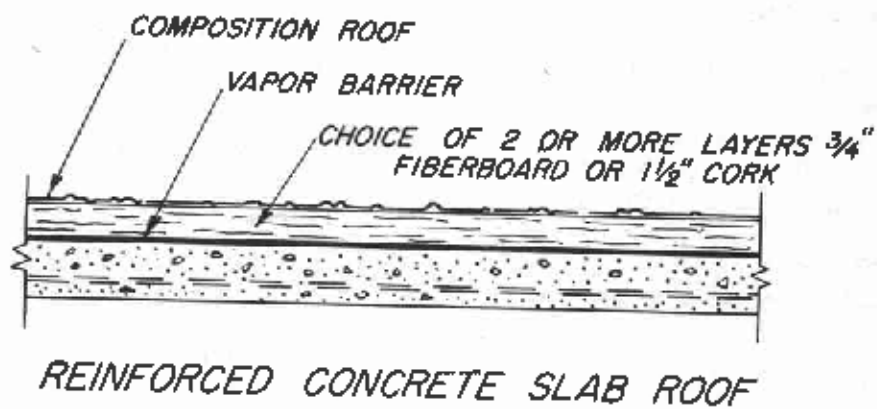


Figure 3. --Roof construction of reinforced concrete slab.

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Partial list of publications
for Furniture Manufacturers,
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Woodshop Practice

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U.S. Forest Products Laboratory

Dry kiln building materials and construction.
3rd. ed. Madison, Wis., The...Laboratory, 1962.
10 p., illus. (F.P.L. rpt. no. 1646)

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