EARLY OPERATING EXPERIENCES
WITH A
SMALL-SCALE DEHUMIDIFICATION KILN

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WOODWORKERS' SAWMILL AND KILN
HEADINGLEY, MANITOBA

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This study was funded under the Canada-Manitoba Partnership Agreement in Forestry. The views, conclusions, and recommendations are those of the author.

EXECUTIVE SUMMARY

A summary of the construction and operation of Manitoba's first commercial small-scale dehumidification lumber kiln is given. The test unit was an EBAC LD 3000 kiln purchased in January 1994. Details are provided as to kiln chamber construction, load preparation, monitoring, and performance with four loads of woods native to Manitoba.

The report is presented within the context of developing a rural micro-sawing industry built around portable bandsaw mills. Lumber drying is shown as the first and most important value-added operation available to the small-scale sawyer. An overview of drying options is given. An outline of current offerings from 3 major manufacturers is included, as well as a bibliography for further reading.

ACKNOWLEDGEMENT

The author wishes to thank the director and staff of the Natural Resources Canada - Forestry Service in Winnipeg for their continued support of research to assist this province's rural small-scale sawyers. Through the various parts of this research and training effort, an emerging industry can find guidance and encouragement in developing methods to better serve Manitoba's woodlot sector.

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INTRODUCTION

This report is the second part of a body of work aimed at rural micro-sawing enterprises. Funded under the Canada-Manitoba Partnership Agreement in Forestry, this research is in support of Manitoba's emerging woodlot sector: the many small-scale sawyers provide a means for the lumber from private woodlots to come to market. A portion of the success of woodlots for those who desire an economic return, then, rests with the skills and attitudes of the small-scale sawyers.

Rural micro-sawing businesses are built around the portable bandsaw mills which have enjoyed recent technological improvements and now offer a sound business investment for rural entrepreneurs. Unlike many of the large circular mills of the past, the new sawyers are likely to be involved in all stages of lumber production from the logging work to the sale of a value-added product. In this manner, the sawyer is in control of the harvesting, sawing, drying, processing and marketing of woodlot lumber and is able to coordinate these activities to result in a level of efficiency not previously possible. Where the wood changed hands many times, was transported often, and followed a circuitous route to the end-user, there was much wasted effort and wasted wood. The sawyer had little idea of the end use for his wood and could only hope to produce a general use dimension for sale into the wholesale market.

For many reasons, the traditional system has changed. Perhaps the foremost cause is a growing recognition that the profitable processes in lumber production (kiln drying and shop processing) often occur far away from the resource harvesting area, probably in an urban area. In our desire for local benefits from local resources, there is encouragement for entrepreneurs who can handle all the phases of production from harvesting to retail sales. A second reason is the realization by sawyers that rising log prices and the higher cost of bandsawing over circular sawing simply results in a perpetually marginal business operation when selling into the wholesale market. Sawyers wanting to support the woodlot movement and to saw in a sustainable manner will continually be undercut by wasteful operations with access to less expensive logs. The wholesale market will only accept the reality of a diminishing wood resource when all other options are exhausted. Thus, to break free of a market determined to depress prices, the rural sawyer needs to take control of the processing of his wood and be able to sell directly to the end users. Many benefits accrue from this new model: local resources provide maximum local employment and local control. Woodlot owners can witness the processing of their wood into a finished product and readily see their fair return for the raw material. Overall efficiency is improved because neither logs nor lumber are transported long distances and then returned as consumer goods. In the face of diminishing oil supplies and concern for pollution, any reduction in the need for transportation is an important change.

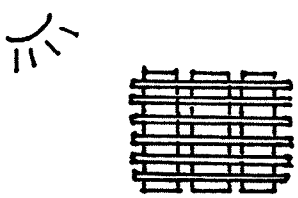
The drying of lumber is really the first and most important value-added process available to the sawyer. While a simple air drying regime may suffice a producer selling only softwood construction lumber, the acquisition of a kiln is what allows a sawmill operator to break the cycle of selling large volumes of green lumber to wholesalers. The ability to dry lumber is necessary before any other processing. A kiln gives one the ability to control and accelerate the drying cycle of lumber.

The reasons for writing this report are threefold. First, to initiate a discussion that will hopefully lead other sawyers to move into kiln drying of their lumber. Secondly, there is a distinct lack of independent information on dehumidification kilns. An interested buyer will find no product surveys, no controlled testing, no comparative operating tests, and no surveys of operators. He has only the manufacturer's information available. While this report is by no means exhaustive, it will hopefully provide a starting point for comparison and provide a look at one operator's experiences in the field. Finally, given that this is the first kiln of its size and type in our area, what adaptations and changes might be appropriate for installations in our cold winter environment? This report will show construction methods intended for our region and begin the process of finding the best solutions for our application.

OVERVIEW OF LUMBER DRYING OPTIONS

There are at least five main options for drying lumber from the sawmill. They are presented here in ascending order of complexity so as to show where dehumidification kilns fall in relation to other drying methods. A more complete discussion of kiln types is given in the first work in this series, Solar Lumber Kilns for Canada's Prairie Region, as well as the general texts listed in the bibliography.

1. AIR DRYING

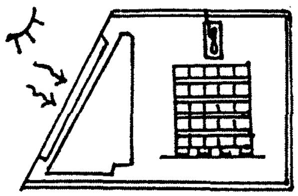


The stacking of lumber for natural or air drying is typically undertaken prior to any kiln drying method, but can also be considered a complete drying system in itself. In its simplest form, the wood is stacked carefully with stickers and protected from rain and direct sun. Protection may be a loose sheet of tin weighted down atop the pile or a proper roof overhead. Sun protection is often provided by hanging sheets of metal or plywood or may include proper walls on all sides. The most elaborate air drying regime would involve placing stickered piles in an unheated building and adding circulation fans to increase air flow. In terms of energy inputs, air drying requires none, unless electric fans are used. Capital cost of this system is very low - just some protective material or an unheated building. Operating costs are similarly low or non-existent. Operating skills required are minimal, although one should not underestimate the considerable body of knowledge that exists in the field of air drying. Such an ancient practise has developed much fact and lore. An excellent text is suggested in the bibliography.

The advantages, then, of air drying are its simplicity, low equipment investment, lack of energy costs, and ease of operation. The disadvantages are that it is seasonal and weather-dependent, is slow and ties up inventory, and offers very little control over the drying process (can result in severe degrade losses.) Perhaps the biggest disadvantage is that air drying in this region will leave the lumber at about 15 to 19% moisture content. While this is marginally acceptable for framing lumber, it is too high for many other applications.

Air drying is often used as a pre-kiln method to remove the bulk of the moisture from sawn lumber thus reducing the time needed for kiln drying. However, the industry is moving away from air drying towards loading green material directly into the kiln. In sawmill operations producing only construction lumber and having good flexibility in delivery times, air drying alone may suffice.

2. SOLAR KILNS



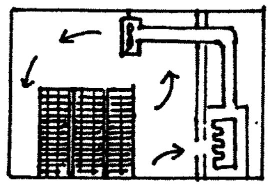
Solar kilns represent the next step in complexity from air drying since they seek to gain some control over the conditions of drying but still employ the sun as the main energy source. In the development of solar kilns, two main types have emerged - a *greenhouse type* in which the lumber is in the solar collector, much as the plants are in a greenhouse space and a second type in which the solar energy is collected in one unit and then pumped into a lumber chamber. The *collector type* is thought to be more workable for serious lumber drying, especially for the temperate zone. This is partly due to the ability to add auxiliary heat to the chamber as desired, to overcome inclement weather and extend the useful drying season. See the bibliography for more detail on solar kilns.

In terms of energy input, the sun provides the bulk of the needed heat, and electricity is needed for circulating fans and controls. It is therefore the least energy-dependent kiln system available, which means that its importance will increase as energy supplies tighten in the future. Capital costs fall somewhere between dehumidification kilns and conventional steam kilns. A solar kiln requires a well insulated kiln chamber not unlike most other kiln types, so there is no major saving with the chamber. The solar collector equipment will be more expensive than a dehumidification unit of similar capacity, but less than steam generating equipment, until the kiln reaches a large scale. As an example, the solar kiln being built as part of this work has a capacity of 20,000 board feet and will cost roughly $70,000 or $3.50 per board foot of capacity. Operating costs will be very low since the only electricity needed will run circulating fans. Estimated energy costs are between $3 and $6 per thousand board feet, based on electricity at 6 cents per kilowatt-hour. Operator skill is minimal, partly because the drying proceeds slowly and includes a daily stress reduction period for the lumber. Maintenance is simple, involving mostly fan inspection and repairs.

The advantages of solar kilns are low operating costs, gentle drying, little monitoring labour input, simple maintenance and the ability to incorporate auxiliary heat from almost any source. The disadvantages are weather dependence, moderate capital costs, and relatively slow drying.

Solar kilns have achieved final moisture contents comparable to other systems (6%), however, they do not lend themselves to operations with very rigid timelines. On the other hand, they are a wise choice for rural areas where inexpensive natural gas is unavailable for heating energy.

3. DEHUMIDIFICATION KILNS

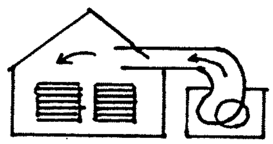


This type of kiln offers the simplest option where the operator has complete control over the drying process. Dehumidification units can be very small - with capacities starting at 250 board feet. Their operation is relatively straightforward - a heat pump or basic refrigeration unit is located inside the kiln chamber. The heat pump has a cold coil (caused by the compressed coolant evaporating) and a hot coil (the result of the condensation of the coolant). Moist air from the lumber pile is drawn over the cold coil where it drops its moisture. The air, now drier, is passed over the hot coil and warmed and then recirculated to the lumber pile. Moisture dropped at the cold coil is led out of the chamber in a pipe and collected. The superior efficiency of a dehumidification (hereafter written as 'DH') kiln over conventional kilns comes from the fact that no warm air is exhausted to the outside - the DH kiln is a closed loop. The heat needed to evaporate the water into the air is recovered at the heat pump. Further, all the inherent inefficiencies of the compressor motor and fans which cause heat are captured in the chamber. Thus, DH kilns tend to heat themselves throughout the drying cycle without actually using a heating coil.

Electrical energy input is modest, and some DH kilns make use of auxiliary heat from other sources. Steam and hot water pre-heat coils can be added to certain units. Capital cost is quite low - the test unit of 3000 board foot capacity cost $5,000 including taxes and shipping from the Toronto area to Winnipeg. An additional $2,500 was spent building a well-insulated chamber using two walls of an existing building. The cost was then roughly $2.50 per board foot of capacity. Operating costs during the winter testing period averaged $3.00 per day, using electricity at 6 cents per kilowatt-hour. Monitoring of the kiln was just a few minutes per day - checking controls, perhaps opening the kiln and testing the moisture content of a sample board. Maintenance and repairs typically require a refrigeration technician as the controls are all electronic and the compressor system requires special tools and equipment.

The advantages of the DH kiln are its modest capital and operating costs, simple operation, and gentle drying cycle while still offering complete control of the process. It is the most energy efficient kiln type in terms of keeping wasted energy to a minimum. Its disadvantages are its dependence on electricity as the principle energy source and the need for technical help with repairs and testing.

4. CONVENTIONAL KILNS

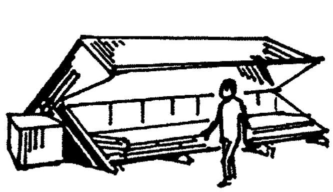


Conventional kilns typically use steam as medium to move heat into the kiln chamber via pipes. Fans force the air over the hot piping and through the lumber pile. Once moist, the air is exhausted outdoors, fresh air is heated and circulated through the pile. Some kilns are direct-fired and use the combustion air as the drying medium, but steam systems are most common. Following a drying cycle, steam may be released directly into the chamber to give a high temperature and high humidity to *condition* the wood - relieve some of the stresses developed during the drying. Steam generators and boilers become expensive when scaled down, so conventional kilns tend to be large capacities.

In addition to electricity to run fans and controls, conventional kilns depend upon large volumes of inexpensive heating fuel. Natural gas, if available, is the best choice for many locations. Unfortunately, using wood residue requires a large scale operation in order to justify the high cost and minimum size of self-feeding wood-burning equipment. Capital costs are quite high, again, due to some practical size requirements for boilers. A small conventional kiln of 40,000 board foot capacity could run $8-9 per board foot if burning fossil fuels, and up to $12 for wood burning (source: FERIC paper presented June 29,1994). Operating costs will depend primarily on the heating fuel costs and vary by location. Bear in mind the significant energy losses inherent in a system that routinely rejects heated air and heats incoming cold air for replacement. Winter operation would be expensive. Operating skills required are high - in addition to monitoring an aggressive drying cycle, the attendant may require provincial licences for steam boiler operation. Probably the largest amount of wood drying information exists for conventional kilns, in the form of very precise schedules, which gives the operator the ability to dry the wood safely in the minimum time possible.

The advantages of conventional kilns are their predictable and well documented performance and rapid drying times. Their disadvantages include the need for trained operators, high energy consumption, and inability to adapt into small-scale operations.

5. VACUUM KILNS



The science underlying vacuum drying has kept vacuum kilns in the research lab for many years. The concept is very attractive - by lowering the vapour pressure from its atmospheric standard of 15 pounds per square inch to a partial vacuum, the energy and temperature requirement to evaporate water are much reduced. For very dense woods which are easily degraded by rapid drying and the attendant high temperatures, vacuum drying offers the seemingly impossible - extremely fast drying with no degrade. Vacuum kilns boast the ability to dry 2 inch oak from green to 6% in a little over one week.

Only recently have vacuum kilns left the laboratory and been made available commercially. The most common unit has a 2,000 board foot capacity and uses aluminum foil 'blankets' laid in between the wood layers instead of stickers. The blankets provide heat electrically, while a vacuum pump pulls a partial vacuum on the chamber. Sophisticated controls monitor and actuate the various functions throughout the cycle.

Energy input is entirely electrical. Capital costs are high - the 2,000 board foot unit currently costs roughly $50,000 or $25 per board foot capacity. In addition, the vacuum pump and blankets have a reasonably short life cycle, four years and one and a half years, respectively. Operating costs are high both for electricity (reportedly $100 per thousand board feet) and for labour since the kiln must be carefully hand loaded incorporating the heating blankets as the layers are built. For custom drying, charges range from $300 to $500 per thousand board feet. Obviously, the load must be a valuable species of high grade in order to justify the cost of drying. Due to the rapid progress of drying, very precise control is needed. The unit demands an experienced operator.

The advantages are very rapid drying of thick and dense woods with minimal drying defects and a compact space requirement. The disadvantages include high capital cost, high operating cost and the need for very precise operation. Vacuum kilns are suited to certain production shops where thick and valuable species are required for 'just in time' manufacturing or as a high-tech. auxiliary kiln in a large drying operation.

In summary, then, there are five main drying options ranging from the time-honoured air drying to the high-tech. vacuum method. Air drying is often used as a pre-drying method to shorten kiln drying times.

In trying to choose appropriate equipment for a micro-sawing enterprise, the first step was to determine the annual volume to be dried in order to make the business viable. It was decided that an annual volume of 100,000 board feet was necessary to sustain a reasonable income and cover equipment costs. A solar kiln of 20,000 board feet was proposed as the 'workhorse' dryer, able to handle five cycles of 60 days each per year. A DH kiln of 3,000 board feet was added to allow some flexibility to handle both small custom drying jobs and small loads needed while the solar kiln is in use with large loads. Figuring on roughly one load per month, the DH kiln adds about 36,000 board feet of annual capacity. It complements the solar kiln in that it is independent of the weather and would be helpful in bridging months of particularly poor solar energy gain.

RESEARCH ACTIVITIES AS A BASIS FOR REPORT

The balance of the discussion in this report is based on operating experiences with a 3,000 board foot DH kiln constructed in the fall of 1994. Specifically, four loads were dried representing a variety of species native to Manitoba, and a variety of thicknesses from 3 inch down to 1/4 inch. As stated earlier, four loads dried in one DH unit cannot provide an exhaustive investigation of the area of DH kiln drying. It is intended to provide a starting point for more information to be recorded concerning these kilns. As to kiln construction, some novel ideas were tried and some departures made from the manufacturer's recommendations. A review of the successes and failures of the construction aspect should prove helpful to those who follow.

KILN DESCRIPTION

An EBAC drying unit of 3,000 board foot capacity was purchased. Following the manufacturer's recommendations for calculating the chamber size, a well-insulated 'box' was built with the interior dimensions of 16'-9" long, 7'-3" high and 8'-6" wide. Both one long wall and one end hinged to open fully for loading and the ceiling was hung from trusses above. The drying unit was mounted on the back long wall with wiring leading out of the chamber to the control unit.

FIRST FOUR LOADS -SPECIES / THICKNESS

The first load measured at least 3,000 board feet and included ash, oak, elm, and basswood, all air dried (but not covered) for at least 18 months. It also included a wide variety of thicknesses from 3 inch to 1 inch. The second load was a similar volume of thinner material, 1/4 inch, 1/2 inch and 3/4 inch, predominantly ash and elm, also well air dried. The third load was 2 inch spruce construction lumber - some very dry and some frozen solid and very wet. And ,

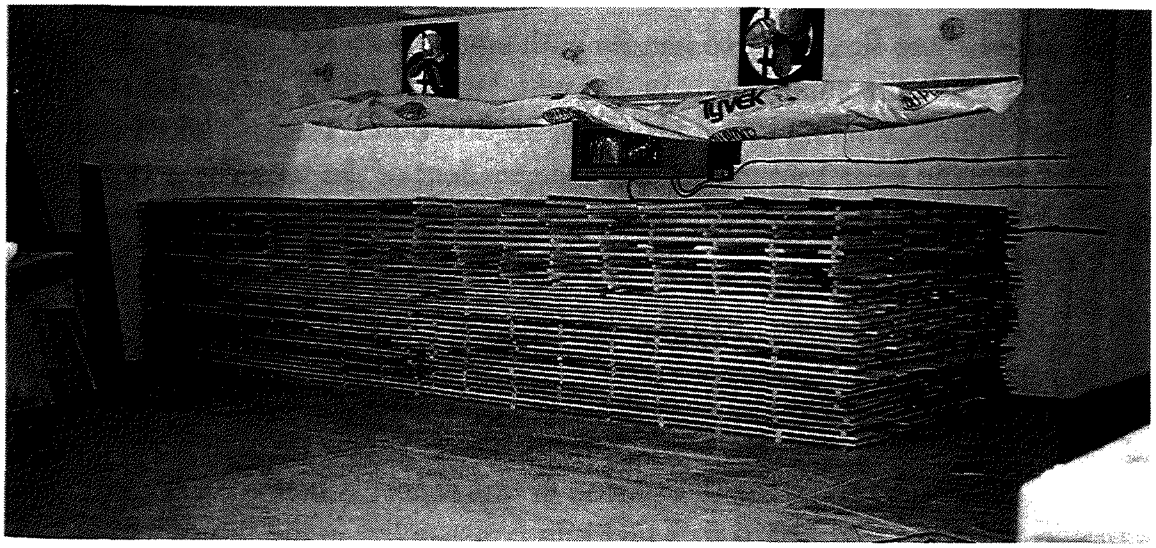


PHOTO 1 - SECOND KILN LOAD - ALL MATERIAL UNDER 1" THICK

lastly, a load of 5/4 elm, air dried one summer, made up the fourth load.

DRYING TIMES

Hardwood loads typically remained in the kiln about four weeks. Entering the kiln in air dried condition, they tested at 18 to 20% moisture content and were dried down to 6% or slightly lower.

The softwood load (third load) was dried 17 days. No air drying was done for this load - a large portion of the wood was frozen solid and very heavy when loaded into the kiln. The balance of the load was at least partially dry coming off the log, cut from near the centre of the tree, and was considerably lighter in weight.

These times should not be taken as an accurate indication of kiln performance. As with any equipment, there is a learning period to go through until one can use the kiln to maximum efficiency. Initially, the manufacturer's guidelines were followed, which are necessarily of a general nature. Temperature was increased by 5 degrees Celsius per day and the duty cycle was 90% until the temperature reached 35°C after which it was 100%.

Information supplied with the kiln estimates a load of 1" hardwood would require 13 days to be dried from 20% down to 8%, or, slightly over two weeks to reach 6%. A load of 2" hardwood would require just under 30 days for the same drying. Given that the first load included some material thicker than one inch, the actual drying time was close to that outlined by the manufacturer. Testing after the drying cycle showed the 2" material to be in the 6-8% range, while the

3 inch board retained a higher moisture content.

The softwood load of 2" spruce seems to have dried at close to the kiln's capacity. From the estimated times table in the instruction manual, a load of 2" softwood is expected to take 32 days to dry from 50% down to 8%. In testing, the load, with an average moisture content of at least 50%, was dried down to 12% in 17 days.

As noted, the actual times for drying the first four loads are poor indicators of possible kiln performance given a more experienced operator. For the purposes of estimating and planning in the pre-purchase stage, one can rely on the manufacturer's information as to drying times, bearing in mind that it is necessarily suggesting a general case. Woods such as bur oak may prove to be near the difficult end of the drying spectrum, and require additional kiln time if drying degrade is to be avoided. Unfortunately, the rich collection of precise kiln schedules available for conventional kilns is not available for DH kilns. These will perhaps become available as more DH kilns come into use, but in the meantime, operators need to compile their own records and learn from experience how to optimize kiln performance for local species. It will be helpful, also, to follow the recommendations given in the USDA's guide, Dry Kiln Operator's Manual - Chapter 7 includes suggestions for adapting the many conventional kiln schedules for use with DH kilns.

As a guide for developing optimum drying times, one can occasionally come across tables of recommended drying rates for a specific species. For example, Wengert (1990) gives a suggested daily safe drying rate for a variety of oaks in his excellent reference work, Drying Oak Lumber. For other species, Table 7-33 in Dry Kiln Operator's Manual gives typical drying times for 1" lumber. Dividing the moisture drop by the number of days will give a rough guide of allowable moisture drop per day.

LUMBER QUALITY AND DRYING DEFECTS

No degrade or drying defects were found in the first four loads. This might be expected because the drying schedules erred on the side of slowness. A complete description of the wide variety of drying defects can be found in the texts listed in the bibliography. To summarize the topic greatly, they include end checking, surface splitting and checking, stains, excessive warp, and uneven moisture distribution throughout the thickness. A small percentage of lumber is expected to be lost to these defects in any drying process including air drying. Some defects are caused at one stage of drying and appear at a later one.

Three of the first four loads were air dried and, thus, a number of defects occurred at that stage. Bur oak left to air dry can easily develop surface and end checking due to excessive sunlight and/or long dry periods of weather. Elm, being very wet when newly sawn, is prone to stain very quickly in warm weather. Based on careful observation, the hardwood loads were judged to have the same amount of defects when loaded into the kiln as when removed. Again, one would anticipate this when the drying regime is relaxed.

The occurrence of drying defects is an indication of severe drying and can be used to establish optimum drying times. The objective is to run the kiln as fast as possible without developing drying defects in the wood. A balance must be found between operating costs, kiln capacity, and losses due to defects. Beginning with a suggested kiln schedule (possibly an adaptation of a conventional schedule) and using careful monitoring, the operator's experience with a given species will lead to optimum kiln performance. Note that not all defects that show up in the kiln are caused by kiln drying. As discussed in detail in various texts, the sawing method, storage, and air drying can set in motion defects that appear in later stages of drying.

MONITORING THE DRYING PROCESS

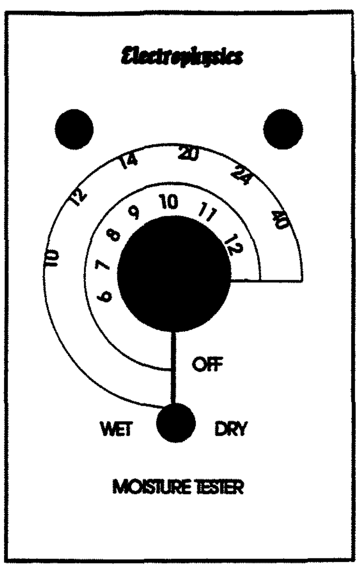


Figure 1-Moisture meter

The basic tool for checking moisture content of lumber is an electronic meter. While more sophisticated methods exist for measuring the water content of wood, these hand-held units represent a good choice for small-scale sawyers. The unit shown, Canadian made, retails for $80-100, and will read to 40% MC. Other units will read to 60% - a useful feature for better monitoring of early stages in drying.

Lumber was checked prior to kiln loading, sampling many boards in various locations (end and surface) to arrive at an estimate of average moisture content at the start of the kiln cycle. To sample the interior of a board, a small section is cut off to reveal a fresh inside surface, or, nails can be driven deep into the wood. In either case, one is trying to take into account uneven moisture distribution throughout the wood - the surface having dried more than the interior.

During the kiln run, the chamber is periodically opened and specially placed sample boards are removed for testing with the meter. This provides an indication of actual drying activity. A time-saving alternative to opening the kiln is to 'hard-wire' several samples into the pile. Nails are driven into samples buried in the lumber pile and copper leads run to a location near the control panel. Following suggestions included with the moisture meter, these samples can be monitored by touching the meter to the wires. This arrangement, although requiring some extra effort during loading, makes it far more likely that testing will be done on a regular basis.

Another monitoring feature that is possible with DH kilns, but not possible with most other kiln types, is to catch and measure the output of water from the dehumidification unit. The heat pump unit typically sits high on the wall of the chamber and has a discharge hose connected to its bottom surface. This may be as much as four feet off the floor, allowing for the positioning of a barrel at the end of the hose (outside the chamber). During testing, the kiln was discharging roughly 20 liters per day which was simple to keep track of in a common 20 liter bucket. The bucket was arranged inside a larger barrel to allow less frequent checking of the kiln. The water volume produced gives a quick and simple check of equipment performance and can be used to indicate when to increase the kiln's dehumidifying rate or when a load is nearing a fully dry condition.

In addition to a daily performance check, one can predict the total water volume to be removed over the course of the kiln cycle. Table 1-8 of Dry Kiln Operator's Manual gives the specific gravity of various species. Recalling that one cubic foot of water weighs 62.4 lbs, and thus, one 'board foot volume' is one twelfth of that, or 5.2 lbs, it is possible to calculate the weight of water to be removed for a given drop in moisture content. For example, take elm's specific gravity of .46 times 5.2 lbs = 2.392 lbs. The weight of water for one percentage drop is then 2.392 divided by 100 = .024 lbs. To drop 1000 board feet of elm from 20% to 6% MC, a drop of 14 points, the calculation is 14 x 1000 x .024 lbs = 336 lbs. which converts to roughly 34 Canadian gallons. This is a more accurate method of calculation than using Table 1-9 of the same book because that table is not adjusted for shrinkage and is inaccurate for this calculation below 30% MC. Above 30%, however, you can find the same result using subtraction of figures in Table 1-9 as you get using multiplication of the specific gravity figures in Table 1-8

Using the same information as above, and knowing the typical daily output of the kiln, one can also estimate the length of the drying cycle. A kiln capable of drawing out 5 gallons of water per day will require roughly 20 days (20 x 5 gallons =100 gallons) to dry 3000 board feet of elm from 20% to 6%, ignoring the time required to warm the load and bring the kiln up to operating temperature.

LOAD SIZING

DH kilns are typically sized according to their capacity with one inch hardwoods. Thus, the unit tested is rated for 3,000 board feet of one inch hardwood, but only 1440 board feet of one inch softwood - roughly half the hardwood capacity. The rating table goes on to show a capacity of just over 5,000 board feet of two inch hardwood, and almost 9,000 board feet of three inch. How are these capacities calculated?

The capacities can be better understood if it is realized that the important factor for the removal of water from wood is not the absolute volume of lumber, but rather, the *surface area*. So a basic capacity of 3,000 board feet of one inch hardwood equates with approximately 3,000 square feet of surface area times two surfaces of the the boards or 6,000 square feet of surface which will give up water vapour. Ignoring the effect of the area on the sides of the boards, it will be readily seen that roughly twice the volume of two inch wood will give a similar surface area of 6,000 square feet, and almost three times the volume of three inch lumber will yield the same surface area.

As to the difference between hardwood and softwood capacity, this is related to the ease and speed with which most softwoods give up their moisture as compared to hardwoods. Again, the calculations are based on the heat pump's ability to remove a given volume of water from a certain square footage of wood. Softwoods will yield up moisture at least twice as quickly as hardwoods, for a given area.

The concept of surface area and kiln capacity is mentioned here because no guidelines are suggested by the manufacturers for loads of material under one inch in thickness. Some value-added opportunities rely on the bandsaw mill's ability to cut hardwoods as thin as one quarter inch or less. When kiln drying these, how does one calculate the kiln capacity? As outlined above, the important calculation is the square footage of the surface area available for water vapour removal. An appropriate load of half inch thick material would be about 1,500 board feet, which would present a surface area of (counting both surfaces) 6,000 square feet. Similar calculations can be done for other thicknesses. Drying times for lumber under one inch will be somewhat shorter given the reduced distance that the water must 'travel' from the centre of the wood to reach the surface and be removed.

DAY-TO-DAY OPERATION

Figure two shows the control panel for the EBAC kiln unit used for testing. Other makers offer similar panels, some with additional features and readouts, some with fewer.

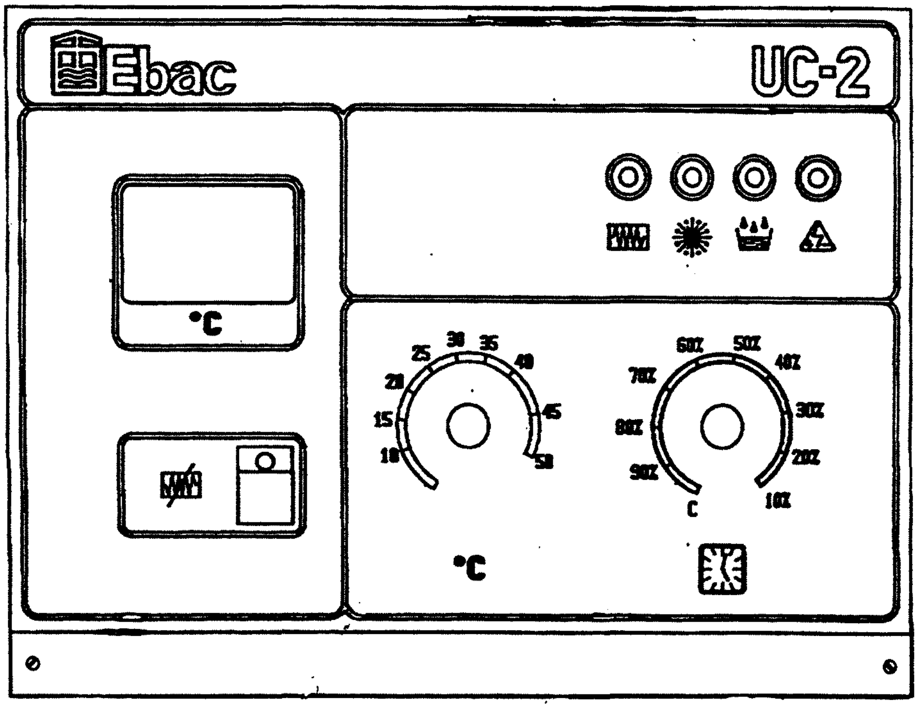


Figure 2 - EBAC kiln control panel

The various indicators and controls are not readily understandable at first glance, so the instruction manual describes each in detail. The two dial switches actually control the operation of the kiln. On the dial denoted 'C ', the operator sets the desired temperature. The digital readout to the upper left shows the actual kiln temperature. The second dial switch marked with a clock symbol is somewhat confusing if one is thinking in terms of percent moisture content. What the dial is actually indicating is percent *duty cycle*, that is, that percentage of the time in which the heat pump operational. A setting of '50%' will cause the heat pump to operate 30 minutes out of every hour. 'C' is the 100% or 'continuous' setting. By controlling the operating cycle of the dryer, one can obtain a drying rate suited to the wood, and also allow a defrost period which is necessary to thaw off ice build-up at kiln temperatures under 35°C.

The only other control adjustable by the operator is a switch that instructs the panel to bypass the auxiliary heat function. A heating coil is built into the dryer unit for use during start-up, and to maintain internal temperatures if the dryer unit is on a low duty cycle. In most cases, the heater coil is automatically activated whenever the kiln temperature is more than 5 C lower than the temperature requested by the operator. The bypass switch will override the control panel's request for auxiliary heat and keep the heater coil out of service regardless of conditions in the kiln.

The remaining indicator lights on the panel indicate the activity of the dryer. The leftmost light is lit when the auxiliary heater coil is in use. The centre left light indicates an overheat condition (kiln temperature is above that requested by the operator). The centre right indicator shows heat pump operation, and the rightmost light shows an electrical malfunction.

Day-to-day operation is very simple and takes only a few minutes. The temperature control is increased a maximum of 5 C per day, within the limits given in a table based on species and moisture content. Duty cycle is left at 90% until the temperature reaches at least 35 C, and then set to 'C'. Certain conditions will require lower duty cycle settings, as outlined in the drying guidelines. A meter test of the load is done periodically, but is most easily done daily is it has been hard-wired to sample boards as described earlier. The last task of a daily check is to measure and/or empty the water discharged from the dryer unit, recording results as desired. All in all, a daily check would take 5 to 10 minutes.

PREPARATION AND KILN LOADING

The proper preparation and loading of the kiln represent a significant cost whether the sawyer is custom drying for others or loading his own lumber. Depending upon the nature of the load and the sawyer's labour cost, the value of the work to load the kiln may easily exceed the operating cost during the drying cycle. During testing, the most easily loaded lumber consisted of 3,000 board feet of 16' 2x6 spruce, which took a total of three hours to load, sticker, apply weights, secure baffles, and close the kiln. The most tedious load was the first one, which consisted of untrimmed and overlength boards in 5 different thicknesses and required 12 hours to assemble into a stickered pile!

Small kilns are usually hand loaded. The size of the pile in the test kiln was intended to be 6' wide, 16'-9" long, and 5'-6" high, using stickers of

3/4" thickness. Such a pile cannot be handled by forklift. Even two piles of 8' lumber would be difficult to move with a forklift given the 6' width. Four piles of lumber 8' by 3' would fill the kiln and could be moved by forklift, but a small-scale sawyer may or may not have such consistent stock all at once.

Several aspects affect preparation and loading, and are presented here in no particular order.

AIR DRYING

As alluded to earlier, air drying is most often a pre-kiln drying method. The bulk of the moisture of green wood can be simply removed with proper air drying and thereby reduce the work required of the kiln. Instead of starting with hardwood at 80% moisture content, or softwood at over 100%, air dried material is often 15 to 20%. This represents a dramatic saving of kiln time. As little as two months of good drying weather will greatly reduce the moisture content of a properly stacked pile of green lumber.

As simple as air drying may appear, there is still a great deal to understand about its proper execution. USDA's Air Drying of Lumber is an important and invaluable text on the subject. It contains a wealth of tables and pictures of many aspects of lumber production related to air drying.

In an efficient small-scale sawmill operation, the lumber would be stickered and stacked directly as it comes off the mill, and moved to an air drying site or unheated building. Note that the stickers need to be ***dry*** material, and not simply edgings produced at the same time as sawing. Green stickers will lead to mould and fungal stains on the lumber surface because the sticker traps moisture but allows oxygen in, setting up ideal conditions for growth.

It is possible that an air dried lift of material could be loaded straight into the kiln after air drying if the kiln chamber accommodates the load size and allows for forklift access. Where possible, this is a great saving in labour.

Photo 2 - lumber piled for air drying on a permanent raised foundation

BOARD LENGTHS AND STACKING

As part of the design of the lumber chamber, the most common board length must be anticipated. Sixteen feet is a frequent choice where a mix of hardwoods and softwoods may be dried. The actual interior dimension of the kiln would be 17 feet or at least 16'-9". This allows for the extra few inches added to boards to allow for trimming and checking. A log bucked to 8'-4" or 8'-6" will eventually yield a full 8' board after trimming off the end-checked portion and squaring up. Two boards slightly over 8' would require almost 17 feet when stacked in the kiln.

Sawmills formerly bucked logs at even foot measures only, that is, 4'-6", 6'-6", 8'-6", etc., however, in the face of tighter supplies, many sawyers buck their logs at any foot measure - 3'-6", 4'-6", 5'-6", etc. When loading the kiln, then, it is handy to have all the various lengths sorted into piles so that layers can be built using all the combinations adding up to 16'. Layers will then be composed of 12's and 4's, 9's and 7's, etc. Where unavoidable, gaps are left in the lumber pile, as described in the notes on 'box piling' in Air Drying of Lumber. The basic concept is that the ends and edges of the pile are complete and spaces occur within the pile. This results in the best possible air-flow through the pile.

MIXED LOADS

The ability of DH kilns to accept loads of mixed species and thickness is often mentioned as a selling feature. The same could be said of many kiln types because the operational reality is that the kiln is only allowed to run as rapidly as the slowest lumber in the load will allow. What is perhaps intended by the claims for mixed loads is that the kiln controls allow precise control and that the operating cost is low enough that it is economically possible to run the kiln at less than peak capacity. As well, the drying is comparatively gentle. However, DH kilns offer no special magic that would allow a tough species like oak to be dried as fast as basswood in a mixed load.

The kiln operating instructions direct one to run the kiln in accordance to the slowest or thickest or wettest species in the load. Drying difficultly is related to wood density and not strictly divided along hardwood and softwood lines. Basswood, a hardwood, dries very easily and performs like a softwood in the kiln. Tamarack, a very dense softwood, would be expected to perform more like a hardwood during drying. Board thickness greatly influences drying difficulty with 2" material requiring more than twice as long as 1" material.

STICKERS

Among the first surprises awaiting a new kiln owner is the number of stickers required to complete a load. A full set of stickers represents a significant investment. For instance, in the test kiln, stickers were 72" in length, and 35 layers made up a full load of 1" hardwood. A 16' long pile might require stickers every foot for a warp-prone species like elm or thin-cut boards. That results in 18 stickers per layer times 35 layers or 630 pieces. Stickers need to be free of large knots so as to remain in one piece during handling, so they tend to be virtually clear material. In size, they may be as small as 3/4" x 3/4" for closely spaced hardwood stickering or 1-1/4 to 1-1/2 wide x 3/4" for softwood drying. And lastly, they need to be dry and of a species that will not react with other woods or cause staining or sticker marks. All things considered, assembling a set of stickers requires a good deal of labour and material.

Basswood is favoured for stickers, if available. In the sawing of carving blocks, the sawyer may have an opportunity to cut stickers out of the discarded slabs or material that is stained and unsuitable for carvers. Similarly, in any sawing situation that results in generous slabs, it would be wise to resaw the slabs for sticker material, especially with spruce or pine which offer a good second choice to basswood stickers. Of course, stickers of the same species are suitable for kiln drying; oak stickers for oak boards, ash stickers for ash, etc.

Further information on stickers is given in Air Drying of Lumber, including stickers of profiles other than flat-faced, and sticker spacing.

LABOUR TO LOAD AND UNLOAD

As mentioned earlier, the labour cost of loading and unloading can exceed the operating cost of the kiln equipment. Bearing mind that the stack will likely be hand-built, the sawyer is well advised to design doors and kiln access with ease of use as the foremost consideration. For this reason, the test kiln was built with both one long wall and one end wall opening meaning that one corner of the kiln opens unobstructed. This is described more completely in the next section. In actual use, access from two sides has meant much better ability to get to the heat pump unit on the rear wall and to get at the back of the pile to line up stickers and straighten boards. If constructed as shown in the manufacturer's literature, one ends up loading a three sided box. Access to the rear of the pile is only possible by climbing over the pile, and the dryer unit becomes both hidden and difficult to reach once the pile is in place and baffled.

Typical loading time should be about 4 to 6 hours for one man. Two people can be kept busy, but the work is not done twice as quickly because the pile progresses in methodical fashion even if a second person places stickers and helps position boards. Using two short stickers to make up the pile width will slow things down, as will the need to trim any boards that overhang the pile edges. Stickers can be stored and moved easily in barrels with casters.

Unloading time will be in the order of 2 hours or less.

STACK WEIGHTING

One function of proper stacking is to hold lumber in place while it dries with the effect of lessening distortion. One might intentionally place a warp-prone species toward the bottom of a pile to take advantage of this aspect. While the lower layers are weighed down by the wood above, what about the top layers?

One solution to try to restrain the upper boards is to use a strong spring-loaded hook securing the ends of a rigid crossbar as described in Air Drying of Lumber. The concept of this jig is to have a sprung hook grab partway down the pile and exert pressure on a steel or wood crossbar, thus holding the upper layers secure. Several such jigs would be required along the length of the pile.

Photograph 3 - stack weighting using concrete test cylinders

Somewhat more primitive, but effective, is to load weights onto the top of the pile. In the test kiln, a layer of 3/4" sheath plywood was laid over the top layer of stickers. Sixty concrete test cores weighing 30 lbs each were distributed over the surface of the stack. Test cores are usually available at no charge from engineering firms that test concrete. Although somewhat tedious to move, the cores were effective in providing pressure to the top layers of lumber.

KILN CONSTRUCTION

Small-scale DH kilns consist of two parts: the mechanical/electrical equipment and the chamber which houses them. Typically, the kiln owner will purchase the equipment package and build the chamber himself, adapting the plans included with the equipment to suit local conditions.

While the kiln may approximate a small garage in size, its construction is much more complex. To have a wood frame building withstand the rigors of very high humidity and high temperatures (75-120°F) requires careful planning and some special materials. Contrary to what one might expect, a softwood kiln requires even more care in construction than a hardwood kiln because the moisture removal with softwood is very rapid and will result in excessive internal humidities possibly cycling every two weeks.

What is the basic configuration of a DH kiln? A 3,000 board foot unit accepting 16' lumber might be described as follows. A stickered lumber pile of 17' length by 6' width by 5'-6" height sits on a concrete or wooden floor. An insulated enclosure surrounds the pile with a gap of roughly 2 feet on each side, but tight on the ends. Running lengthwise in the chamber and hung from the ceiling is a divider holding two circulating fans of 24" diameter. A heat pump/fan unit (approximately 3' by 3' by 1' deep) is hung on one long wall or sits atop a stand. One or more walls open to allow loading of lumber, and a small control panel is wall-mounted outside the chamber. A hose or pipe is connected to the dryer unit and leads the collected moisture out of the chamber. Electrical service to the chamber will include a 220 volt line for the heat pump and a 120 volt line for the circulating fans. Additionally, a second 120 volt line may be used for lighting inside the chamber.

In this section, the construction of the test kiln will be described as well as some of the manufacturer's recommendations. Suggestions are offered to help the prospective kiln builder to plan his work and make appropriate choices as to design and materials. The main concerns affecting kiln construction were priorized as follows:

1. ease of access when loading
2. good insulation and seals
3. maximum durability for a reasonable cost

Arriving at an appropriate kiln structure for any given situation will necessarily involve balancing these priorities and compromising as needed. It is the intent of this section to familiarize the builder with the factors affecting the decisions made throughout the planning process.

CHAMBER SIZE

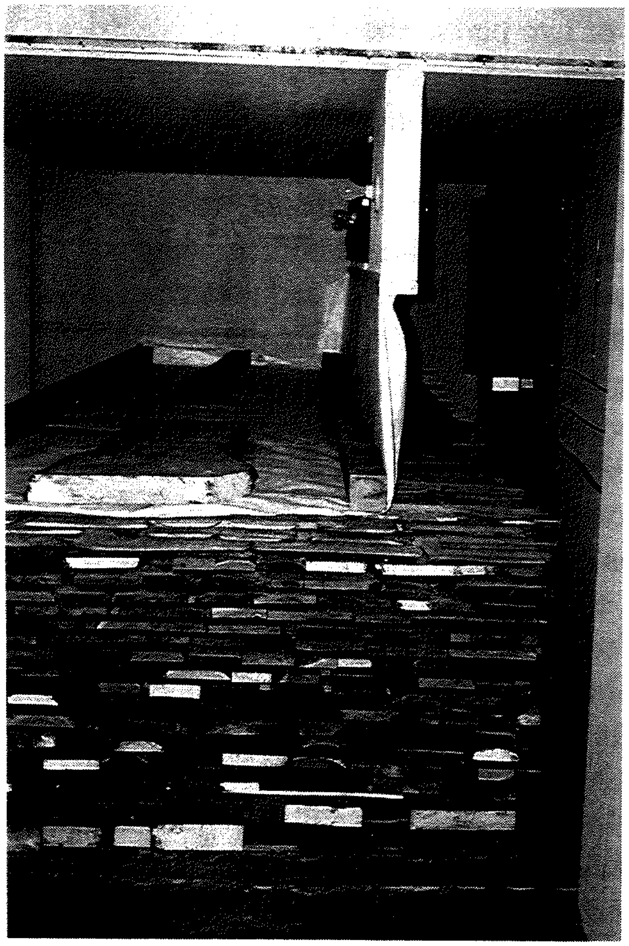


Photo 4 - stack in relation to dryer unit

The first step in determining chamber size is to calculate the most desirable pile length for your application. The manufacturer's literature is helpful in this regard. The test kiln was designed to accept 16' material which resulted in a pile 6' wide and 5' high. The calculation was simple: 16' by 6' gives 96 board feet per layer (using 1" lumber). It requires 32 layers of 96 board feet to reach kiln capacity of 3,000 board feet. Each layer will be 1-1/8" thick plus a 3/4" sticker for a total of 1-7/8". Thirty-two layers at 1-7/8" equals 60".

To the lumber pile size, the manufacturer's suggest adding certain allowances. Overhead, a 2' allowance for installing the circulating fans. On each side, an allowance for the fans to build pressure in the air flow. In large kilns this is called the 'plenum space' and is roughly equal to the sum of the stickers. In the case mentioned, 32 stickers at 3/4" would give a plenum space of 24". One can follow the manufacturer's (EBAC) suggestion for adding 15" to each side or increase to 24". As shown in Photo 4, a 15" allowance is very tight if one needs to get at the dryer unit while the kiln is loaded, or if one has to access the innermost side of the pile to align boards or stickers. Another manufacturer, Nyle, suggests much more generous allowances on the sides of the lumber pile.

The test kiln was sized 16'-9" interior length in anticipation of some 16' lumber, but more commonly, 2 pieces 8'-4" end-to-end. Note that any gaps remaining on the end of the stack when completed will need to be plugged or baffled in order to direct air flow through the pile instead of around the ends.

In calculating stack width, 6 feet seems to be the maximum advisable - some manufacturers favour widths of 3 or 4 feet to ensure good air circulation.

INDOORS OR FREE-STANDING?

Having calculated the stack size and chamber size, the next major decision is whether to build a chamber in an existing building or to build an entirely free-standing kiln chamber. This is a decision with many pros and cons involved, not all of which are obvious. Central to the decision is remembering that you are constructing an insulated box with internal temperatures of 70 to 120°F and high humidities, while the outside temperatures may be below -20°F, for winter operation.

A free-standing kiln has need of excellent seals on all doors and openings to keep out cold winter air and maintain low operating costs. As well, how is the collected water to be handled? Is there a way to collect it without risk of freezing pipes? An obvious added cost to a free-standing kiln is the roof structure and exterior finish which would be unnecessary for a chamber built indoors. Loading will be done outdoors for a free-standing kiln and the chamber will become chilled during loading.

A kiln chamber built indoors has the advantage of dealing with a less severe surrounding climate. Even an unheated shop or barn space is more desirable than the outdoors when trying to create an insulated chamber space. Some of the other savings are obvious - the possibility of using existing walls for a portion of the chamber, an existing floor, ready access to electricity, etc. While the chamber still needs good insulation to maintain low operating costs, one has the consolation that leaked heat contributes to the warming of the shop space, rather than leaking outdoors as with a free-standing kiln. But note, also, that any air leakage from the kiln will carry considerable humidity with it. A kiln located in a woodworking shop, for instance, may contribute to an unacceptably high humidity in the shop. Again, good seals on the kiln doors are among the most important and difficult aspects of construction, both for retaining heat and retaining humidity. A kiln built indoors will tend to be easier to load assuming there is sufficient free space to sort lumber and open large kiln doors.

Clearly, the simplest option for chamber construction is to locate the unit in an existing building. However, a free-standing unit is also feasible provided one can build carefully to combat our cold winters, and has carefully planned how to go about water disposal and loading.

DOOR DETAILS

While the construction of a tight well-insulated chamber poses no great problem for a builder used to construction in this region, the provision of large doors that seal tightly is very difficult. Many options are possible depending on the builder's skill, the materials available, and the allowable expense. This is an area where the prospective kiln owner needs to plan very carefully to arrive at a workable solution.

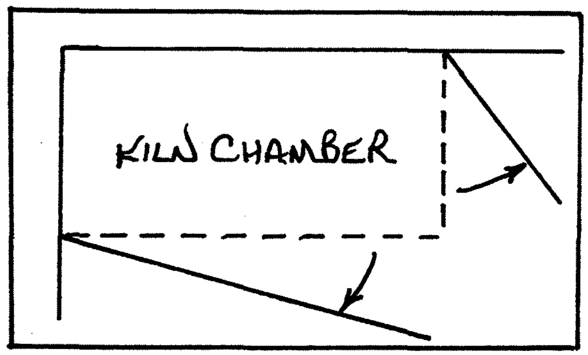
First off, decide which wall will open and how big the doors will be. Ease of loading long lumber dictates that one of the long walls should open as completely as possible. The realities of obtaining good seals dictates that the doors be as small as possible. Well insulated doors, even going to the expense of extruded styrofoam and aluminum, quickly become too heavy and awkward to be feasible. Wood framing makes even heavier doors. The manufacturers suggest pairs of hinged doors, either on the long wall or an end wall. While this may be the best solution in the final analysis, even a four foot wide door seven feet high is a heavy unit considering it may be more than 6 inches thick to accommodate insulation. Can the hinges carry this load? If using a pair of four foot wide doors, will an eight foot opening be satisfactory for lumber loading on a bi-weekly or monthly cycle?

One idea often suggested is to hinge the door along the top edge, and thus, raise the door rather than swing it open. This has been shown to be workable on an 800 board foot unit. Note that the weight of the door presents a safety concern should it ever close unexpectedly. Large doors suspended overhead would be a definite safety risk and are not advised, especially where employees or the public may have access.

Door seals deserve careful attention, especially for free-standing kilns. Many seals are meant to be crushed between two surfaces, while others simply push tight against one surface. Crush seals typically have a small tolerance for sealing - for instance, the ability to seal gaps not less than 1/4 inch but not more than 3/8 inch. These are difficult tolerances to maintain in construction. Common edge seals may have greater ranges but seal less effectively or may relax over time and seal poorly. Some of the latest built-in plumbing fixtures make use of an *inflated* rubber seal which is not widely available yet, but may be able to be improvised by a builder. The idea is that the doors would be closed on deflated seals and then air pumped in to swell the rubber against the surfaces.

Unfortunately, no 'ideal' seal can be recommended for this application. The builder is left to choose among many less-than-perfect options.

The 3,000 board foot test kiln employed some novel solutions to the problem of large operable doors. Two walls of an existing shop were used for the kiln chamber, with the remaining two wall were actually hinged doors. That is, an 18' by 8' high 'wall' was hinged at the corner to form the chamber side wall and a second 'wall', 9' by 8' high was hinged to form the chamber end wall. In operation. both walls are swung away and one has excellent access to the lumber pile with no obstructions.



There were many complications to this system. First, the ceiling had to be hung from the shop trusses, because the hinged walls could offer no support. The hinged walls were very heavy (800 and 400 lbs) and had to be carried on several casters which support the weight during opening and closing across the concrete floor. Due to slight variations in the floor, a special hinge able to accept up and down movement had to be fabricated. When closed, clamps are needed to pull the doors' meeting corners together and make a seal. Was it worth the effort to build such doors? They do operate smoothly and are simple to use. The unobstructed access to the kiln is appreciated with every loading and unloading. At nine inches thick, they are well insulated. But it was a lot of work to get all the details worked out.

CHAMBER CONSTRUCTION -FLOOR AND FRAMING

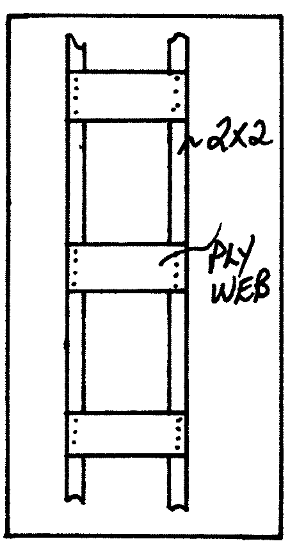
Free-standing kiln plans as offered by the manufacturers may need some revision to suit our extreme climate. For instance, a builder would not normally extend a concrete pad out under the walls because this conducts cold into the floor, in spite of a styrofoam cover applied to the exterior. Rural builders will recognize that such a kiln building could be best built with 'pole barn' techniques: treated posts set into pre-drilled holes in the ground at intervals of 4 or more feet. In that case, the concrete pad 'floats' within the perimeter walls and is isolated from the cold exterior.

In general, a free-standing kiln chamber for our area should reflect the best elements of the R2000 home construction standards, because the service is much more severe than a house must endure. Pole barn techniques lend themselves to thick wall cavities which may be insulated with fibreglass or cellulose material, wrapped in air barrier on the exterior and carefully lined with vapour barrier on the interior surface. Ground insulation may include 2 or more feet of extruded styrofoam laid around the *outside* of the building, sloped away and buried several inches for protection. The advice of an experienced builder should be of assistance in creating a proper kiln enclosure for a moderate cost.

Kilns build indoors are less complex to construct, but still require attention to detail. Even a heated shop will be many degrees cooler than the interior of the kiln, so adequate insulation is important.

As cautioned by the manufacturers, while heat loss is a concern for cold weather operation, overheating is a concern during warm weather. If the kiln is over-insulated with no way to remove insulation for the summer months, then the kiln will be in a constant state of overheating. Heat is a desirable by-product of the operation of the heat pump during winter operation - it helps maintain kiln temperature without using the heating coil. But in summer, the heat may become excessive, so that the lumber is damaged by being too hot at an early stage of drying. The controls will detect that the chamber is warmer than the operator has requested and shut down the heat pump. No moisture will be removed until the chamber cools below the requested temperature, at which point the heat pump will cut in. Obviously, this continual overheating cycle is not conducive to good drying or favourable operating costs. An exhaust fan unit (possibly available as an option) allows some flexibility in dealing with overheating, but a better solution is to be able to easily remove insulation from the chamber. The insulated ceiling provides the best opportunity for accessing and removing insulation and construction of a free-standing or indoor kiln should anticipate this possibility.

The test kiln, as mentioned, used two walls of an existing shop built in the pole barn style. These exterior walls were 12" thick and included 9" of cellulose insulation and 3" of fibreglass batt. The ceiling and opening walls were constructed using Larsson trusses' as is sometimes done for energy-efficient home building. A Larsson truss involves using light vertical members held apart with intermittent plywood or particleboard webs. One creates a thick wall using very little material, with a substantial saving in weight. In this case, 2x4 material was split to 2x2, and 3/8 plywood webs 9"x4" were used to build the trusses. The resulting light members were used on 16" centres to form the doors and ceiling, and insulated with fibreglass batts. The entire ceiling was hung from the shop's trusses. The insulation in the ceiling remains easily accessible should its removal for summer operation be warranted. All door seals used double rows of 3/4 inch ethafoam rod compressed to 1/2 inch upon closure. The ethafoam was an inexpensive choice for trial, but a better seal material is being sought with improved durability.



INTERIOR FINISH

What material is suitable for the kiln chamber's interior surface? Its main function is to protect the vapour barrier and thus prevent moisture from penetrating the insulated wall structure. An exterior grade of plywood is commonly used: a 3/8 or 1/2 spruce sheathing plywood would be the closest material to 'CDX' plywood or marine plywood, as suggested by the kiln manufacturers. True marine plywood is available in Manitoba, but only by special order and at considerable extra cost.

Some experience with a new drywall product has been gained in the test kiln. In an effort to find an alternative to plywood that would offer a small measure of fire resistance, Louisiana-Pacific's ***FIBREBOND*** *Fibre-Reinforced Gypsum Sheathing Panels* were used for the stationary walls and ceiling in the test kiln. (Sheathing plywood was used for the doors.) This product is not to be confused with exterior drywall sheets or drywall for damp locations. Rather than a paper facing, it has a cement-like face and back where the gypsum/cellulose mixture has been pressed with extreme pressure. It accepts screws well and is highly resistant to surface damage in normal use. Fibrebond offers a similar fire resistance to normal drywall. Currently priced in the range of $400 per thousand square feet, it is slightly cheaper than 3/8 plywood. An added feature is that it is made from recycled materials.

Regardless of the choice of sheathing material, fastener holes need to be filled to prevent corrosion. Common autobody filler, a fibreglass resin based product, is acceptable for this purpose. Reduce the required catalyst to slow the otherwise rapid setting time and work quickly with small amounts. The sheathing should be spaced slightly apart during installation and filled with body filler before painting or caulked after painting. It is important that moisture does not gain access to the edges of plywood or the edges of the drywall board.

An aluminized mobile home roofing paint is suggested by the kiln manufacturers for the entire surface of the interior. Various high quality vapour barrier-type paints are also available. The test kiln was painted with Bondex's Alkyd Pool Paint and seems to be holding well over the gypsum board.

Corners and any open joints need to be caulked with a high grade exterior caulking compound to complete the seal inside the kiln.

ELECTRICAL LAYOUT

Wiring details supplied with the kiln equipment are quite complete and should be followed carefully. You may wish to add a circuit to handle lighting in the chamber, and locate the switch beside the switch controlling the circulating fans. For safety, given that the circulating fans are perhaps 5 feet off the floor, they are usually switched off before entering the kiln. (They should also be covered with a wire cover for safety's sake.) Switching off the circulating fans does not affect the dryer unit which has its own internal fans.

If possible, have the kiln dryer at hand when planning the electrical layout. The 220 volt power cord must reach the intended receptacle, usually outside the chamber. The location of the controller is limited by the length of the control cable.

For the design of the test kiln, there was only one possible location for the 220 volt receptacle, and the power cord reached far enough, however, it was necessary to extend the control cable several feet in order to reach near the power outlet. It was also necessary to recess the control unit (about 12" wide by 9" high by 6" deep) into the wall surface to allow the door to open flat in front of it. If departing radically from the manufacturer's recommended location for the controller, one could specify a longer cable at the time of purchase and avoid splicing cables together on site.

BAFFLES

As noted earlier, baffles are used to direct the air flow through the lumber pile and to prevent short-circuiting of air around the ends or over the pile. A hinged baffle is usually suggested, hung from the bottom of the circulating fan divider. It may also be necessary to use foam or wood baffles to block off the ends of the pile if there is a gap left after loading.

An alternative is the use of *TYVEK* or similar building wrap, as was done in the test kiln. These papers are windproof and very strong. They can be rolled up and tied so as not to be in the way for loading. During the drying cycle, they are rolled down to reach the top of the lumber pile and extend partway across the surface, weighted to remain in place as needed. (NOTE: Nyle Corp. warns that this material may be a safety risk if it comes loose and lodges in the fans.)

CONSTRUCTION COSTS

It will be readily seen that there are too many variables in the choice of materials and methods to allow a realistic estimate of costs for a given situation. Hopefully, enough information has been given to allow a prospective owner to prepare a realistic estimate of the materials and labour suited to his own case.

In the case of the test kiln, the chamber was constructed as described and the wiring installed for a material cost of close to $2,500. Not included was the cost of providing the existing two exterior pole-type walls which had exterior sheathing, but no insulation, at the start of work on the chamber. Also not included is the value of the concrete floor under the kiln, which was in place prior to chamber construction. And finally, no cost is assessed for the labour of construction, estimated at 80-100 man hours of skilled labour.

DH KILN EQUIPMENT CURRENTLY AVAILABLE

The prospective DH kiln buyer is fortunate to have at least three reputable suppliers of small-scale equipment. It is very much a matter of deciding among several good choices.

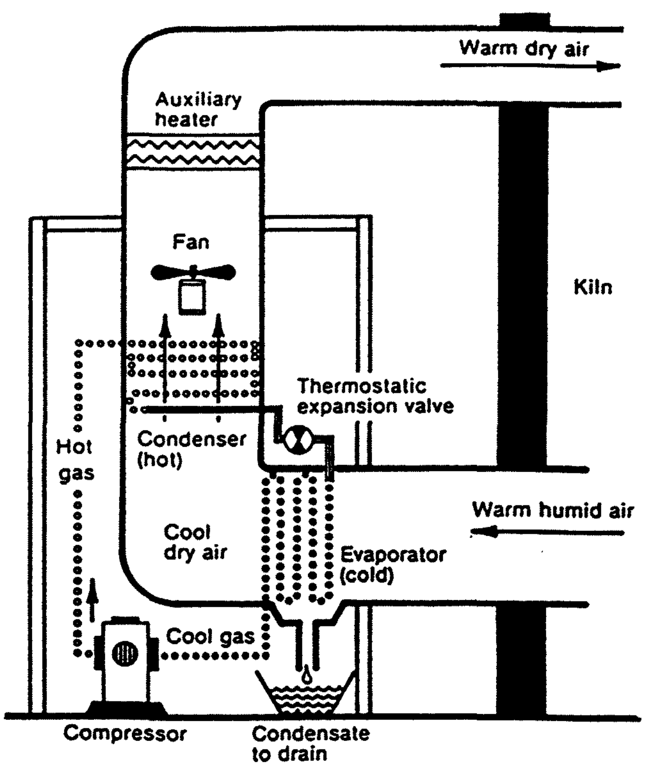


Figure 3 - DH kiln schematic

A review of the operation of the dryer unit will suggest what might be important to consider in choosing equipment. As shown in Figure 3, the heart of a DH dryer is a heat pump or refrigeration unit. The operating principle is that a gas becomes warm when compressed and cool when decompressed. Warm moist air from the lumber pile is passed over the cold coil and drops its moisture, which is piped out of the chamber. The air continues on to pass over the hot coil where is becomes warm, and thus, dry. If additional heating is required, a resistance heater cuts in. The warmed, dried air is then returned to the lumber pile to cycle again.

The quality of the heat pump components and controls is critical to the durability and capacity of the DH kiln. These must be industrial quality parts designed to run full-time if the kiln is going to work well day in and day out.

One could priorize the important aspects of a kiln purchase as follows:

1. *quality of heat pump components and controls* - it is beyond the scope of this report to make comparisons among the various manufacturers as it would require controlled testing of all units in a laboratory setting. However, it can be said that the buyer should carefully compare the capacities of the various units and ensure that similarly powerful equipment is being offered by various makers to give similar kiln capacities. Look for horsepower ratings or 'volume of water removed per day' ratings. This allows one to evaluate actual drying capacity per dollar spent. Bear in mind, also, that environmental concerns have led to the phasing out of traditional refrigerants, R-12 among them. By the close of 1995, no more of this material can be manufactured so all supplies will be recycled, and prices will rise accordingly. One would expect a reputable kiln manufacturer to now be offering units with the newer refrigerants. Enquire as to which refrigerant the supplier is currently using and be sure it is not one soon to be obsolete. While it is possible to switch from the older to the newer refrigerants, the cost of purging and cleaning the heat pump is modest with some equipment and prohibitive with others.

2. *operating information and product support* - given that small-scale DH kilns are relatively new and operating information quite scarce, one has to rely on the manufacturer to share their accumulated experience with new owners. Beyond operating instructions, owners will benefit from technical back-up for trouble-shooting both in written form and by telephone. Especially rural kiln owners will want to be able to make minor repairs and adjustments themselves before having to call a refrigeration technician for help.

3. *access to current owners in the region* - it is always helpful to talk to a current owner about his experiences with the particular equipment you are considering buying. The owner can comment on the quality of the components and his dealings with the company. Was the operating information adequate? How has the equipment performed? How did the company respond to problems? Has the equipment performed in accordance to the claims made in company literature? A reputable manufacturer will direct you to current owners in your area so that you can make such enquiries.

4. *a Canadian sales outlet* - this is really a matter of convenience, but it is easier to make a purchase in Canadian currency and avoid the task of importing equipment through brokers and shipping agents. Where no Canadian outlet exists, be sure to find out what the manufacturer is prepared to do simplify the delivery to your location. Some equipment sellers are able to quote a firm price in Canadian currency that includes all applicable duties, taxes and delivery costs, greatly simplifying your purchase decision.

The three major suppliers of small-scale DH kilns, presented alphabetically, are:

1. DRYLINE SYSTEMS, Mississauga, Ontario.

Dryline offers 4 small-scale models - DL10 with 1hp compressor for 2-3,000 board foot capacity, DL20, 2 hp for 3-6,000 board feet, DL30, 3 hp for 6-9,000 board feet, and DL50, 5 hp for 9-15,000 board feet (hardwoods). Models DL10, 20, and 30 are 'standard temperature' dryers with a maximum temperature of 128°F, while the DL50 is a 'high temperature' unit able to reach 150°F. (See note below regarding standard and high temperature units). Dryline has one large-scale DH kiln installation in Winnipeg, and is an original equipment manufacturer using North American parts. Replacement parts not available locally are supplied from its two warehouses.

2. EBAC SYSTEMS, Williamsburg, Virginia.

EBAC offers 3 small-scale units ready to go, plus larger units on a custom basis. The LD800 is rated for 800 board feet of hardwood with a maximum temperature of 113°F. The LD3000 is rated for 3,000 board feet of hardwood and has a maximum operating temperature of 122°F. The Mainframe 2 model is rated for 3 - 5,000 board feet of hardwood, with a maximum temperature of 140°F. No compressor horsepower ratings are given in EBAC's literature or manuals, but rather, kilowatt ratings are given: LD800-0.320 kW, LD3000-1.10kW, and the Mainframe 2- 3.5kW. A 41 page manual comes with the dryer unit and includes all the chamber design drawings, installation and testing information, operating instructions, wiring diagrams and troubleshooting notes. Information strictly related to operating the kiln occupies 7 pages. EBAC is an original equipment manufacturer using both European and U.S. components, and has many installations in Canada and the United States. Canadian sales are handled through a representative near Toronto. Current owners in this region include the author and units in Dryden, Thunder Bay and Ear Falls, Ontario.

3. NYLE STANDARD DRYERS, Bangor, Maine.

Nyle offers 2 models for standard temperature operation (max. 120°F): the L-50 with 1/2 hp compressor rated for 1,000 board feet hardwood and the L-200 with 2 hp compressor for 3,000 board feet of hardwood. Four models make up the high temperature offerings: L-300 with 3 hp compressor for 6,000 board feet, L-500 with 5 hp compressor for 10,000 board feet, L-1200 with 12 hp compressor for 24,000 board feet, and l-2500 with 24.5hp compressor for 45,000 board feet. Nyle has by far the most informative literature, chamber blueprints and operating manual. The chamber plans and operating manual are available for $50US, refundable if purchasing a dryer unit. The operating manual is worth the cost because of a wealth of tables, articles on lumber drying, and extensive bibliography for further reading. Nyle is an original equipment manufacturer and handles Canadian sales out of the Bangor office. Upon request, they will send listings of owners in this region: 14 in Ontario, 46 in Wisconsin, 32 in Minnesota, 2 in Alberta and 1 in North Dakota.

NOTE: ***STANDARD AND HIGH TEMPERATURE UNITS***

Most DH units with capacities of 3,000 board feet or less operate under 140° F which provides gentle drying. Units able to attain temperatures of 160° F are useful in speeding moisture removal under 30% MC, cutting drying times by as much as half during this stage. The trade-off is that they can stress the wood to the point of necessitating a conditioning cycle after the drying cycle if the lumber was loaded green, although this can be fairly easily dealt with. Drying wood at higher temperatures may induce colour changes in certain species.

INCREASING DRYING CAPACITY

With so many variables affecting a sawmill's ability to dry lumber, it may be difficult to pinpoint the ideal size of kiln at the outset. Certainly the business plan will suggest what level of production is needed annually to sustain the business, but finding the right kiln to perform the work may be a problem. One suggestion offered is to purchase a small DH unit to start and add more units later to increase capacity. Rather than trying to establish a large kiln, one ends up with a few smaller units. One advantage of this concept is that it offers more flexibility for handling a variety of woods as might arise in a custom drying operation. Loading can be staggered so as to produce some dried material every week or two rather than once a month.

CAPITAL AND OPERATING COSTS

To summarize the costs noted elsewhere in this report, the dryer unit cost very close to $5,000Cdn including taxes and shipping in January of 1994.

The kiln chamber required $2,500Cdn in materials, not including some of the pre-existing features as noted. In spite of a complicated door system, it would be hard to imagine building a good chamber for any less money, while a free-standing unit would cost at least twice as much. All these costs assume that the operator is able to perform the construction labour himself.

The equipment cost, then, is:

drying unit - 5,000
chamber - 2,500
total - 7,500 (3,000 board foot capacity)

or, for a free-standing kiln:

drying unit - 5,000
chamber -5,000
total -10,000 (3,000 board foot capacity)

On a cost per board foot basis, the least expensive one could expect would be $2.50 if building a chamber indoors, or $3.35 if building a free-standing unit.

Operating costs for drying air dried hardwood might be as follows:

loading - 5 hours @ $20	100.00
30 days operation @ $3/day	90.00
unloading - 2 hours @ $20	40.00
maintenance - 1 hour @ $20	20.00
total	$250.00 for 3,000 board feet or $83 per thousand.

Operating costs for drying air dried softwood might be as follows:

loading - 4 hours @ $20	80.00
15 days operation @ $3/day	45.00
unloading - 2 hours @ $20	40.00
maintenance - 1 hour @ $20	20.00
total	$185.00 for 3,000 board feet or $62 per thousand.

Note that operating times would decrease with operator experience, as the drying unit is run closer to full capacity. Take these figures to be conservative.

The above figures would represent labour and energy costs to the business for drying its own stock. No allowance is made against the capital cost of the kiln or repairs. In a custom drying situation, one would expect to recover some of the other costs of the kiln beyond simply labour and energy expense. Twenty dollars per hour is not entirely wages but includes the added costs of self-employment or employees - insurance, bookkeeping, overhead, etc.

CONCLUSIONS

Small-scale DH kilns represent a viable drying option for the rural micro-sawyer and allow predictable volumes of lumber to be dried for a reasonable labour and energy cost. The technology is simple and the chamber can be built by an owner with moderate construction skills and experience.

A 3,000 board foot capacity unit would occupy roughly 170 square feet of floorspace in an existing shop (ignoring room needed to open doors) or could be constructed as a free-standing unit. Careful planning is needed regarding door opening and sealing details in order to create a well insulated chamber.

Capital costs for a 3,000 board foot unit will likely not be less than $7,500 for a kiln built inside an existing building, or $10,000 if built free-standing. These are material costs only, and include no labour allowance. Estimates reflect 1994 material prices in Manitoba.

With electricity at 6 cents per kilowatt, and labour with overhead valued at $20 per hour, air dried hardwood could be dried to 6% for approximately $85 per thousand board feet, and air dried softwood could be dried for approximately $65 per thousand board feet. These figures represent initial operating experiences and one could expect costs to decrease and annual capacity to increase as the operator gained experience with the unit,

Prospective buyers will find a good selection of DH kilns ranging in capacity from 800 to 45,000 board feet, with kilns under 3,000 board feet tending to be simply operated standard temperature units (120°F max.). Larger kilns tend to be high temperature units offering improved performance and requiring more highly skilled operators. Three major companies currently manufacture DH kiln equipment aimed at the small-scale market.

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