SOLAR LUMBER KILNS
FOR
CANADA'S PRAIRIE REGION

BURTON BORYEN

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

As part of a research and development project to encourage small sawmill enterprises in rural areas, an introduction to wood drying concepts and kiln drying is presented. A review of relevant research to date on solar lumber kilns is used to develop a set of design parameters for a solar kiln. A discussion of kiln requirements for portable bandsaw milling businesses on an owner/operator basis and a business plan are given. Finally, a design for a 20 thousand board foot solar kiln for use in the Prairie Region of Canada is proposed. Prepared under contract to Natural Resources Canada - Canadian Forest Service and funded through the Canada-Manitoba Partnership Agreement in Forestry

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PREFACE

This report, which will focus on solar kilns, is part of a larger project undertaken by the Canadian Forest Service and the Province of Manitoba aimed at providing the necessary research and development to foster sustainable micro-sawing enterprises in rural areas. Begun in April 1993, the project combines recent advances in thin-kerf sawmills and small scale lumber kilns with clear thinking on woodlot management and sustainable forestry. The first business of this kind operates under the name of Woodworkers' Sawmill and Kiln, and it is both a demonstration project which uses small scale equipment, and a research shop conducting the necessary development work to improve the viability of micro-sawing in this region.

How shall Manitobans move toward 'sustainable forestry'? Certainly the concept of woodlot management is a good starting point. Let a 'woodlot' be defined as a privately or publicly owned wooded area which is managed for multiple benefits over the long term. 'Sustainable development' in forestry addresses both the environmental aspect (the well-being of the forest) and the economic activities carried on in the forest. At present, the production of lumber is the largest single economic activity in Canadian forests. Sustainable forestry requires that we do more than simply harvest lumber at the rate at which the forest can replace it. Truly sustainable forestry must address the long term well-being of the entire ecosystem if healthy forests are to be passed on to future generations.

In the struggle to change to more sustainable practises, what is likely to happen to the economic aspect? In many cases, a move towards sustainability will mean less wood harvested. Does sustainable forestry then mean a net loss of economic benefit? Unless our current methods are rethought, then yes, the economic benefit from our forests will decrease.

If Manitobans wish to maintain or increase the value of our forest resource in the face of reduced timber supply, the logical path is to become much more clever in the way we harvest, process, and market the available supply. If account is also taken of the direction that the world is headed in terms of such issues as, for instance, energy supply, then we can begin to formulate an approach that will result in a truly viable long-term forest industry.

Some of the needed changes involve the use of more appropriate equipment such as thin-kerf bandsaw mills and tractor-mounted logging winches for the woodlot. New equipment needs to be evaluated for its overall fuel efficiency, wood produced per gallon, even though the cost of fuel may not be critical at this time - the environmental cost of over-dependence can only rise in the future. Any serious look at the energy inputs into forestry would have to examine wood drying, which currently consumes up to 70% of the energy used for wood production.

But newer equipment will only provide a short term advantage for our industry unless the operators are willing to pursue more thoughtful and complete processing and marketing. Certainly Manitoba has many small industries that manufacture finished products from wood, but the waste and inefficiency that occurs between the forest and the end user is staggering. It is a mystery to many woodlot owners as to why almost no native hardwoods, except the lowest grades, are used in our secondary wood-using industries. To bring our own hardwood resource to market, we will need more informed sawyers who know the end use of a board before they cut it from the log. They also need to be skilled in value-added processing, be it kiln-drying, planing, special sizing, producing kits-of-parts, or special products. When the Forest Engineering Research Institute of Canada (FERIC) profiled over a dozen micro-sawyers in Ontario, among the most successful was a business that bought logs and sold cabinets.

Is the move towards sustainable forestry simply a drive to become 'ultra-efficient' in processing? While improvements in efficiency are needed, such single-mindedness would lose sight of the desire to have the economic benefits of forestry remain in the forested regions, in the rural areas. The argument for economies of scale has tended to result in centralized industries which offer only a bare minimum of employment close to the resource, with all the high value processing accruing to the larger centres. Some of the newest sawmill complexes are mechanically impressive but offer very little employment compared to the volume of resource consumed. In a wiser scenario, evaluation of our forest enterprises might include consideration of which model provides the greatest *employment per log*. If the object is to encourage sustainable forestry enterprises for the rural areas, then the value-added processing components must be able to be carried out in those same rural areas.

In summary, the larger project to encourage rural micro-sawing enterprises seeks to combine the most appropriate equipment with the greatest possible value-added opportunities. This report looks at kiln drying, specifically solar kilns. The reader is introduced to the topic of wood drying and current kiln technology. An examination of solar energy basics leads into a discussion of solar lumber kilns, and the kind of research to be found in the literature. Finally, the argument in favour of solar lumber drying is presented along with design details for a kiln appropriate to the Prairie region.

All material contained in this report is geared specifically to small scale bandsaw mill enterprises using native woods in the region roughly limited by Kenora, Ontario on the eastern side and the Saskatchewan-Alberta border to the west.

Every attempt has been made to give a non-technical presentation of the concepts that a reader would need to understand in evaluating the appropriateness of a solar kiln for this region. Any number of fine texts are available for the reader who desires a more detailed discussion of any aspects presented here.

INTRODUCTION TO DRYING WOOD

Volumes have been written concerning the drying of lumber. So large is this body of knowledge that texts can be found that cover the drying of wood from just one species of tree. Wengert's book, Drying Oak Lumber, is an example of the depth of information currently available. What is needed here, however, is a broad overview of the topic. One cannot adequately consider kiln design and operation without at least a rudimentary understanding of the task that the kiln is trying to accomplish.

Woodworkers have struggled with wood's high moisture content since woodworking began. For many woods, half the weight of the green log is water, and at least as much effort has gone towards dealing with this water as has gone into using the wood itself. Even at the logging stage, long ago lumbermen were careful to leave the crown and branches on the log until the needles withered, thus ensuring that at least a portion of the moisture had been drawn out. Some round log builders were eager to use the green log immediately because it responded so well to the axe and its considerable weight was helpful in making the logs fit closely. Others demanded that the log season two full years in a carefully constructed pile sheltered from the sun and rain. Both methods required allowance for settling and shrinkage in the completed wall.

Carriage and furniture makers had fewer options. Texts of the day simply stated that, "there should be a goodly supply of well seasoned timber on hand." All lumber was air dried, for up to seven years. A rough shed was typically used - lots of ventilation but no direct sunlight or rain on the lumber pile. Most craftsmen allowed a further period of time for the wood to adjust to the shop's humidity, and might also do a final seasoning of the jointed parts in the home before assembling the piece. It should be noted that these simple methods yielded very fine lumber and the multitude of wooden articles that have survived are a testament to the durable and stress-free wood produced by patient air drying.

THE BENEFITS OF DRIED LUMBER

What is there about *dried* lumber that causes woodworkers to wait so patiently for it? What changes does the wood undergo to justify such an expenditure of time and effort in the drying process?

The benefits of drying lumber are many. For nearly every use wood is put to, removal of the high moisture content is essential. Among the benefits are:

1) **stability** - after the shrinkage and deformation of drying, wood is much less likely to further react to internal stresses. (Some internal stresses can remain in dried wood, however, and may appear during sawing or machining operations.)

2) **strength and stiffness** - drying results in significantly stronger and more rigid lumber as the cell walls lose some of their elasticity.

3) **the ability to hold fasteners** - nails, screws, and staples are designed for use with dried wood and hold very poorly in green lumber.

4) **the ability to be glued** - adhesives and glues must penetrate the wood's surface in order to make a bond; surface moisture prevents glue penetration. Additionally, moisture may interfere with the curing process of an adhesive.

5) **the ability to hold finishes** - like adhesives, oils, varnishes, paint, etc. must take hold on a dry and stable surface.

6) **durability and decay resistance** - moist wood becomes a home for fungi and molds while dry wood is much less attractive to decay.

7) **reduced weight and easier handling** - a significant portion of the weight of green lumber can be removed by drying.

Clearly, the improvements in wood's qualities underscore the importance of drying. And yet, the nature of wood itself imposes many restrictions - it seems to accept drying only grudgingly.

HOW WOOD DRIES

Before looking at some of the kinds of defects and problems that wood encounters during the drying process, it is necessary to understand a little more about the way in which water separates from wood. The details of this process can be described at length, but there are two concepts that are central to the topic: *free water* and *bound water*.

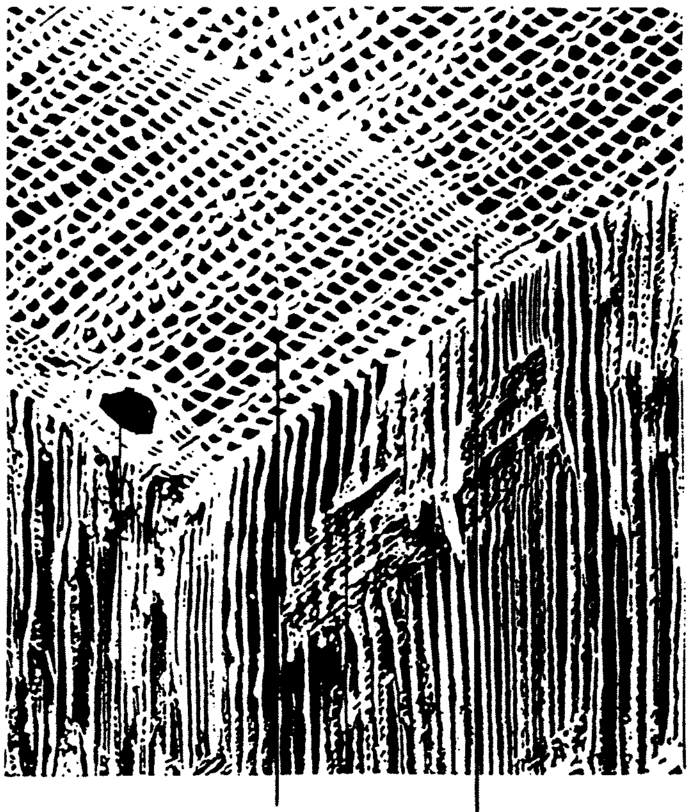
Figure 1 illustrates the nature of wood cells and shows the location of free water and bound water. The important points to note here are: (1) that the loss of free water is relatively easy and does not affect the size of the wood cell; and, (2) the loss of bound water is more difficult and results in a change of cell size.

Wood gives up its free water comparatively easily, although the process can still take some time because the moisture lying at the centre of a two inch thick block must 'travel' a full inch to reach the surface and evaporate. The loss of free water is occurring from the green lumber stage down to roughly 30% moisture content. As mentioned, the next stage will bring about more drastic changes, so kiln operators mark this point where drying switches from free water to bound water as the **fibre saturation point.** The term simply recognizes that the free water formerly in the cell cavity is gone, but the cell walls (fibres) are still saturated.

It is important to bear in mind that the nominal moisture content of a piece of wood is not a precise and consistent indication of moisture content at every point throughout the wood. The outermost layer of wood reacts very quickly to the humidity around it, while the centre of the wood reacts very slowly. The objective of good drying, then, is to achieve as homogeneous a moisture content as possible throughout the wood, and to arrive at a moisture content that is at equilibrium with the surroundings for the end use of the wood.

As soon as the outermost wood begins to fall below approximately 30% moisture content, stresses are set up within the wood. Recall that the wood below the surface is more moist. The outer shell is shrinking while the core remains swelled. This and other structural problems caused by uneven shrinkage, plus various problems with molds and chemical changes are grouped under the name **drying defects**, also loosely termed **degrade.**

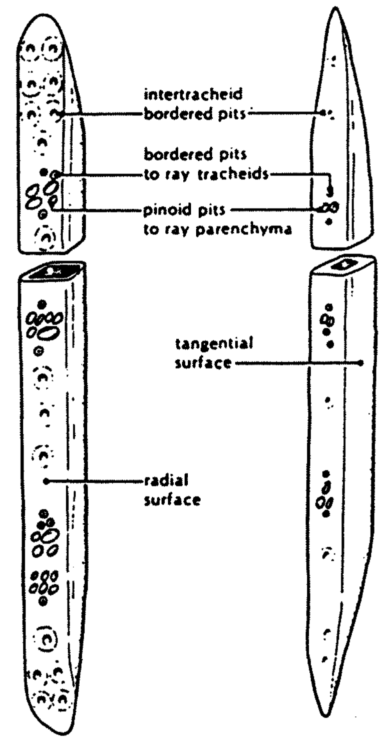
Figure 2 shows some important points on a graph of drying from green to completely dry.



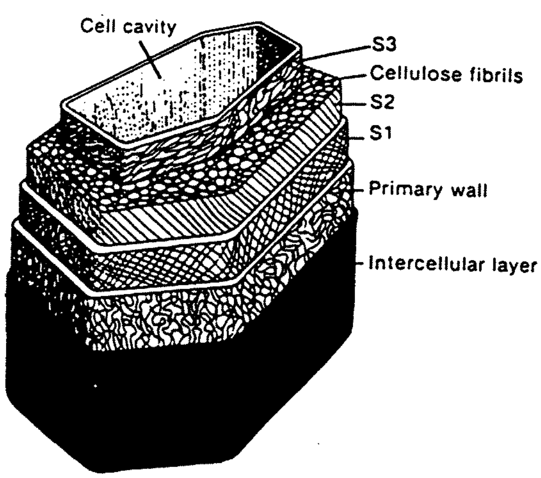
earlywood cells latewood cells

75X magnification of lodgepole pine

earlywood cells latewood cells



cells in softwood



cross section of wood cell showing several layers of cell wall

FREE WATER is held in the cell cavity

BOUND WATER is held within the cell walls

FIGURE 1: WOOD CELLS AND THE LOCATION OF FREE WATER AND BOUND WATER

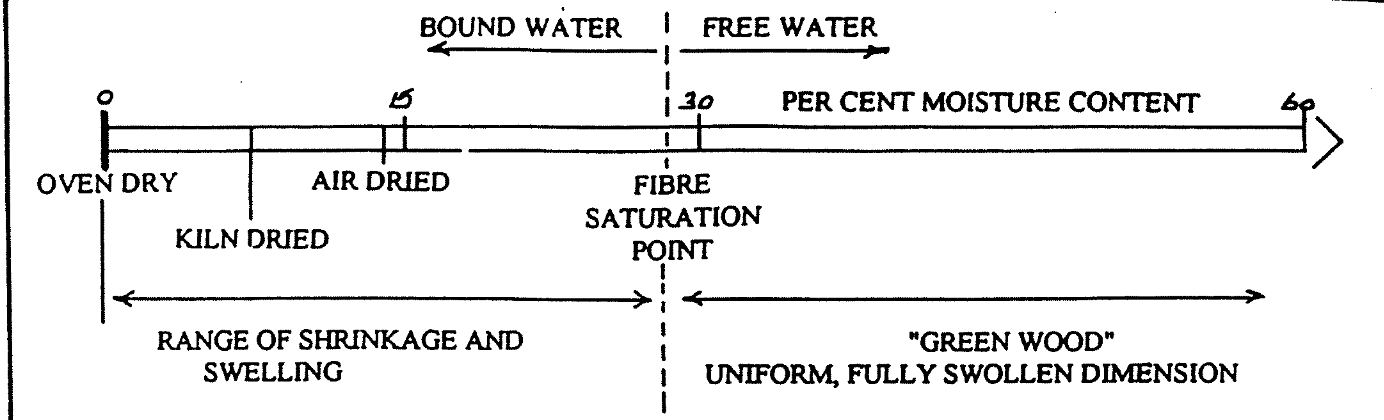


FIGURE 2: IMPORTANT POINTS ON THE DRYING SCALE

THE PITFALLS OF DRYING - DRYING DEFECTS

As noted earlier, wood does not accept drying entirely gracefully. There are many potential problems lurking in the drying process, any one of which can virtually ruin the wood for its intended purpose. Broadly grouped, there are four categories of defect:

1) rupture of wood tissue - uneven shrinkage through a board can cause failures in the structure of the wood.

2) warp - differences in shrinkage cause deformations in the the wood due to the orientation of major axis in the wood and/or the presence of reaction wood.

3) discolouration - as temperature increases, chemical changes can occur that cause staining of the wood by its own sap. Additionally, fungi and bacteria can attack and discolour the wood.

4) uneven moisture content - individual boards within a kiln load may dry insufficiently or unevenly and be rejected from further processing.

Figures 3, 4, and 5 illustrate some pronounced drying defects. The reader is directed to the many good texts that deal with drying defects at length. It is perhaps sufficient to note here that improper drying can do great damage to wood, rendering it unsuitable for its optimum use and far less valuable than otherwise possible.

Although many defects are attributed to the drying process, it is more accurate to say that many defects appear at the drying stage, but can be caused in earlier handling stages or even result from the tree's growing conditions. Excessive wind and sloping sites can produce trees with severe internal stresses. Improper falling methods and poor or lengthy log storage can initiate defects. Uncontrolled drying, air drying, or pre-drying errors can set in motion checking, warpage, and staining. Despite the general reference to 'drying defects', the cause of some defects is to be found in earlier stages.

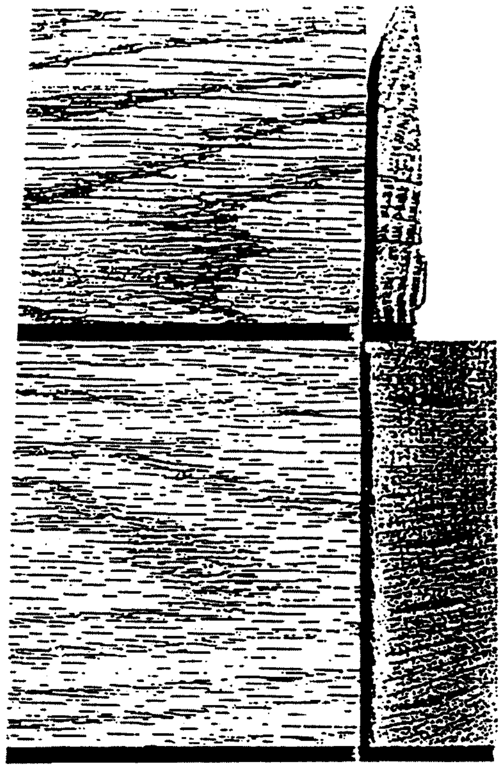


FIGURE 3: HONEYCOMB IN OAK THAT BECAME VISIBLE AFTER MACHINING INTO MOULDING

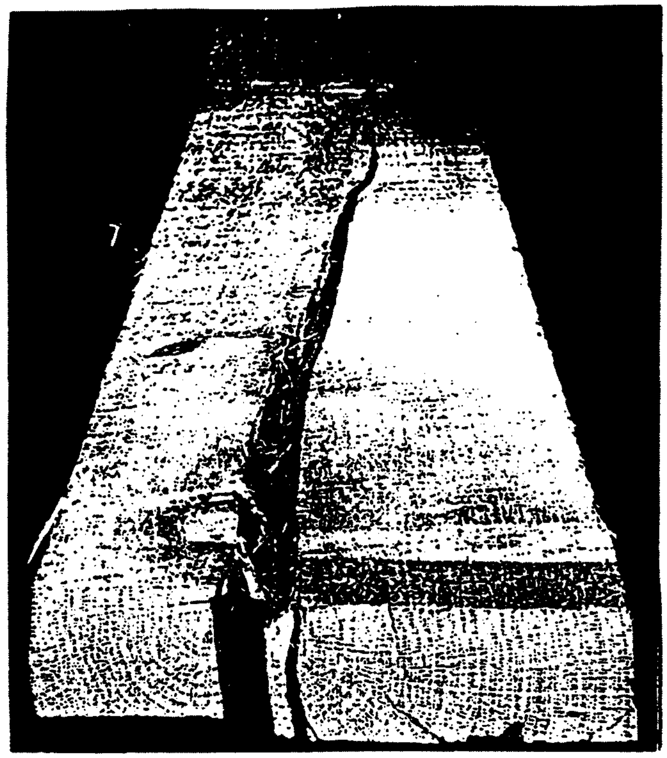


FIGURE 4: BOXED HEART SPLIT

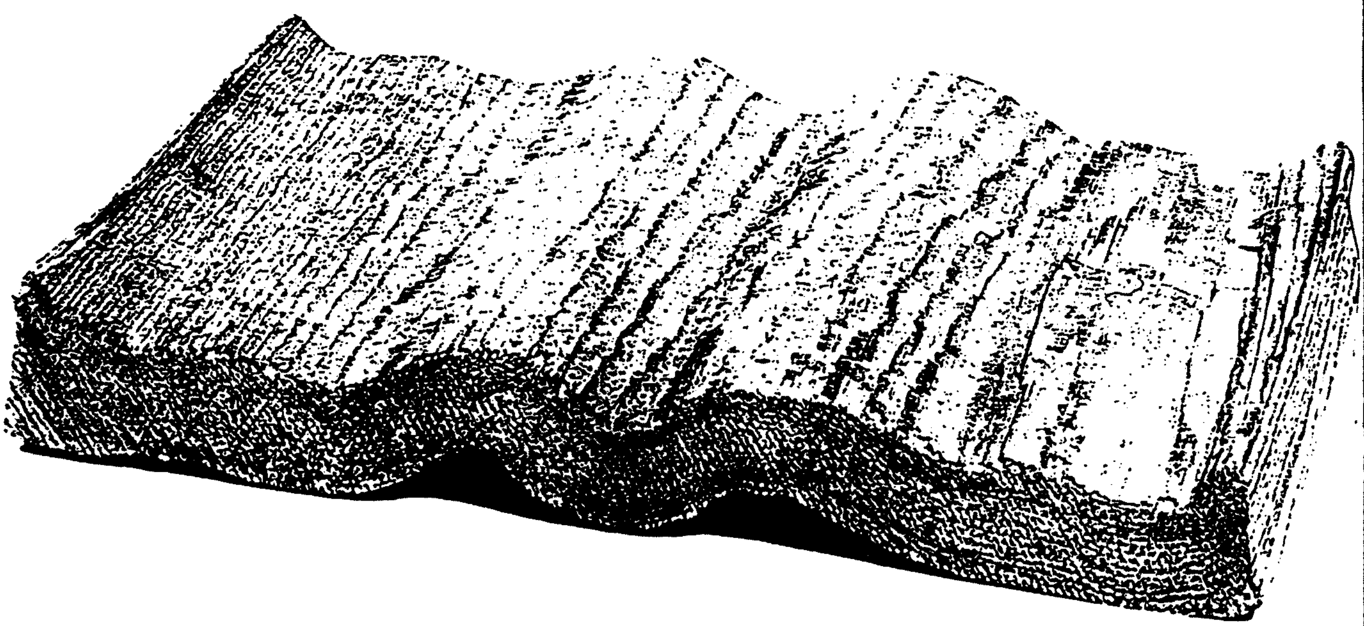


FIGURE 5: SEVERE COLLAPSE IN CEDAR

Once cut from the stump, wood will inevitably lose moisture to the surrounding air. Our task is to try to control the drying conditions and avoid the many defects that can occur, and this is true whether we choose an air drying regime or the most sophisticated kiln.

DRYING DIFFICULTY BY SPECIES

Is oak more difficult to dry than pine? Anyone who has handled various woods will have an intuitive sense that hardwoods like oak might be harder to dry than softwoods like pine, and this is more or less true. In general terms, softwoods accept drying more easily than hardwoods, but it would be wrong to assume that all coniferous woods go through a kiln with ease while all deciduous woods are more difficult.

It would be helpful to plot native woods on a line running from the most simply dried to the most difficult, so that one could exercise due caution in handling each species. The density of the wood gives some indication of its willingness to be dried, and this makes sense if we recall that the moisture from the centre of the wood will have difficulty passing to the surface if the wood is very tightly structured. We could also consider how much water is contained in the wood at the outset - its average green moisture content - as an estimation of how large the drying task will be. 'Tendency to warp' has been assigned to most species and this provides another aspect to determining overall drying difficulty.

Appendix A lists Prairie species beginning with the most easily dried and progressing to the most difficult. Density, green and dry weights, moisture contents, average air dry and kiln dry times, and a comment on special drying problems is shown. In any attempt to rank order such a variable material as wood, one's experience may suggest a different order. There can be great variation within a species like oak from one region to another, and dependent upon a whole range of factors starting with when the tree was felled, how long the log was stored before sawing, how the sawn boards were handled, and so-on. The table is intended as a rough guide only. Appendix A also includes a generally accepted listing of tendency to warp, and tendency to check.

MOISTURE CONTENT AND END USE

What moisture contents are acceptable for various purposes?

Wood is typically not dried any more than is necessary for its end use - why invest more energy and risk more degrade if the wood's performance for a certain application is not improved? Over time, woodworkers have established the level of dryness appropriate to various tasks. As noted earlier, some log builders use only green logs because the ease of working wet wood with an axe is the main consideration. For certain furniture and equipment parts, wood must be *riven*, or split rather than sawn, and this can only be done with certain moisture conditions. For general construction work, softwoods at about 12-15% moisture content are a good compromise between ease of nail insertion and holding ability. Exterior work and implement parts will stabilize at 12-15%. Mouldings and interior trim typically contain about 8% moisture, while musical instruments, furniture, and flooring are closer to 6%. Figure 6 shows moisture content for various lumber applications in Canada.

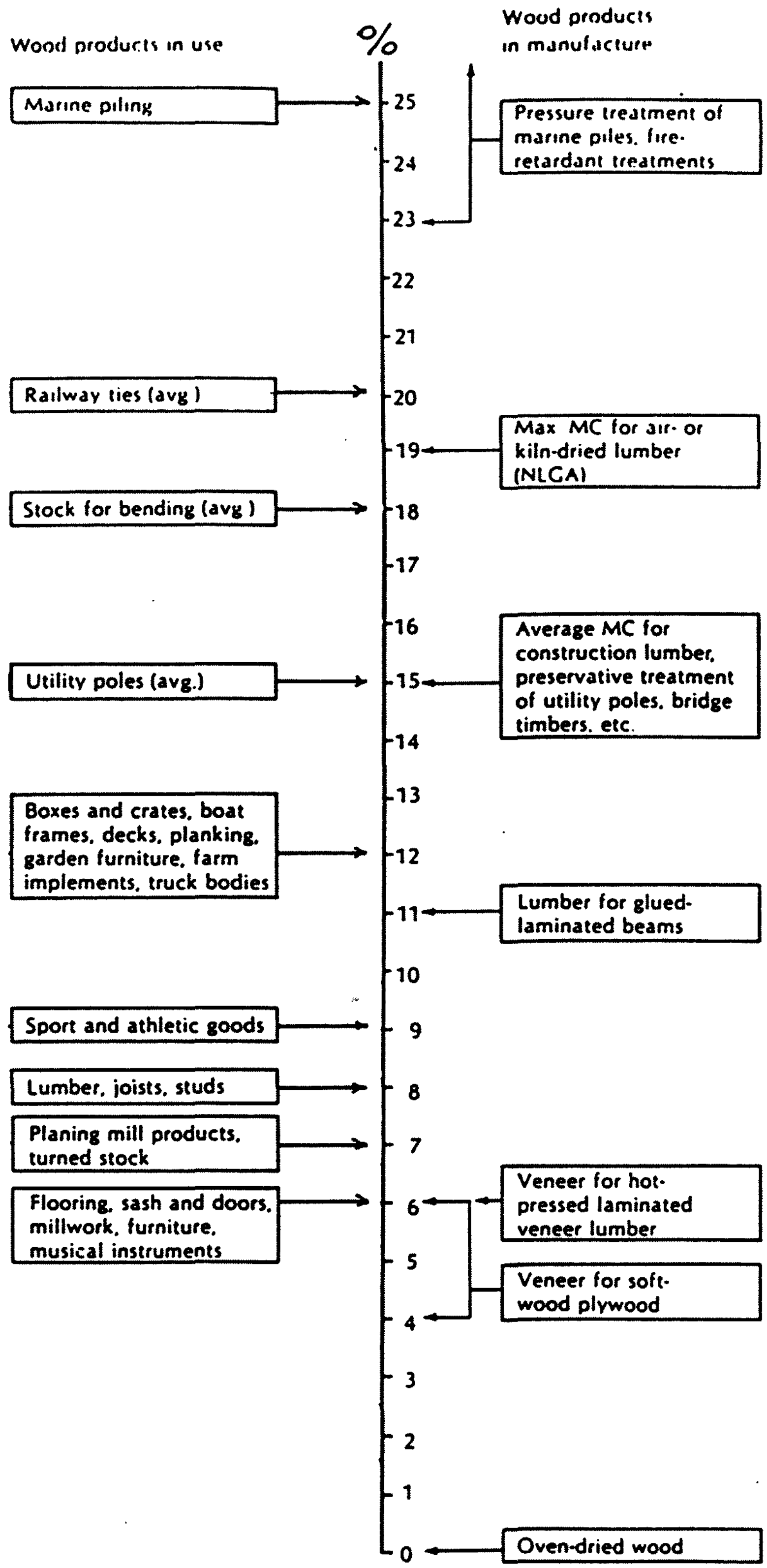


FIGURE 6: MOISTURE CONTENTS OF VARIOUS CANADIAN LUMBER PRODUCTS

INTRODUCTION TO KILN DRYING

In the previous section, both the reasons for drying wood and the problems that arise in the process were examined. Historically, air drying was the only method available and craftsmen learned to accept its rules beginning first with a generous time allowed for outdoor drying and then one or more periods of seasoning in a workshop or living space. As to the quality of the wood produced in this fashion, antique furniture and interiors suggest that this was excellent wood. We know less about the amount of material that was lost to degrade.

Lumber kilns are simply our attempt to gain control over the variables of lumber drying, especially time. In one sense, the kiln is another *tool* that we use to work with wood, and like any tool, it imposes certain rules and has limits.

There are several aspects that arise in evaluating the many different kiln types that have evolved. One can address the rate of production, the cost of operation, the skill level of the operator, and so-on, but the overriding concern is the quality of the product. There would be little sense operating a kiln that turns construction grade green lumber into fuelwood, or a drier that begins with green furniture grade lumber and finishes with pallet stock. All the evaluation factors of kiln operation are secondary to the assumption that the kiln yields the same quality of lumber as was loaded into it.

Before looking at the types of kilns available , let us define the task that kilns perform and the basic methods available to do that work.

THE KILN'S TASK AND METHODS

Lumber kilns have a simple overall purpose: to **control** the drying conditions around a lumber pile. Most kilns have only three methods by which to do this:

1) apply heat - the application of heat encourages the evaporation of water because evaporation is a process that absorbs heat. Additionally, raising the temperature of the surrounding air lowers its relative humidity and further encourages the wood to give up its moisture.

2) move air - fans are used in kilns to ensure that warm dry air is constantly available to all lumber surfaces as evenly as possible. The intention is that the air in the kiln not be allowed to settle into layers of temperature or pockets of high humidity.

3) control humidity - once the air has taken moisture from the wood, there must be some way to pull the water out of the air. Some kilns simply exhaust moist air and replace it with fresh drier air, while other systems actually remove water from the circulating air and recirculate.

These are the three basic processes available in a kiln drying situation. Some advanced kiln types employ a partial vacuum or heating by microwave, but the majority of kilns are limited to ordinary heating, air movement, and dehumidification techniques.

If lumber drying is essentially a physical process of evaporating the water out of wood and into the air, **how much energy** does it take to accomplish this? In absolute terms, one can simply calculate the energy needed to evaporate a given volume of water and the energy needed to raise the temperature of a volume of lumber and come up with a total energy input needed in the drying process. In a theoretical sense, the number may be true and useful. But it tells us almost nothing about how much energy a given kiln needs to perform the task.

The estimation of the energy inputs for kiln drying is complex. In fact, the amount of energy needed to evaporate the water is among the least important considerations because it is constant from one kiln to the next. The energy needed to evaporate 1600 lbs of water from 1000 board feet of elm (from green moisture content of 90% to 6%) can be calculated as 1,600,000 Btu. But the same energy will be required in any kiln. There can be no magic in the physical world. What is of importance in determining the energy needed for drying is the energy expended in moving air, dehumidifying air, and the efficiency of the heat generation. One must also consider the losses throughout the system plus the duration of the process - how many days must a kiln be maintained at a given temperature?

One can immediately see that the energy requirements of a kiln system will be dictated by such factors as the insulating value of the kiln chamber, the outdoor temperature and humidity, the size of the fans, the type of heat source used, the tightness of the kiln doors, the amount of venting to the outside, the skill of the operator and so-on. All in all, it would be a very complex calculation. From actual kiln operation it is generally accepted that conventional kiln energy consumption is 2 to 2-1/2 times the heat of evaporation.

How, then, can one compare kiln systems as to energy consumption? Such comparisons can only be done in terms of 'more than' and 'less than' statements. Where absolute numbers are cited, they tend to come from surveys of actual kiln operations where the amount of fossil fuel and electricity used can be divided by the amount of lumber dried. Even with such a figure in hand, there is no way of knowing which of the many variables is contributing to what degree.

TYPES OF KILNS

At least seven different types of lumber kilns are in use or under development in Canada. Figure 7 gives a very simple picture of each one, ordered by complexity starting with air drying. (More detailed drawings of solar, conventional, and dehumidification kilns are given in later discussions.) If one considers that some kilns combine two types into one unit, then there is indeed a wide variety of lumber drying operations underway.

This report does not investigate vacuum, microwave, and freeze drying kilns. These units involve more advanced technical features than the other kiln types but offer some impressive improvements in certain areas. Vacuum kilns are gaining popularity in operations where thick hard-to-dry lumber is needed in minimum times. The reader is encouraged to compare the latest testing and results with these kilns along the same parameters laid out here.

However, for the purposes of this report, and as a general principle, it is perhaps best to try to move towards the more simple rather than the more complex. Only when all of the simpler answers have been proven unworthy do we need to look towards more technical solutions.

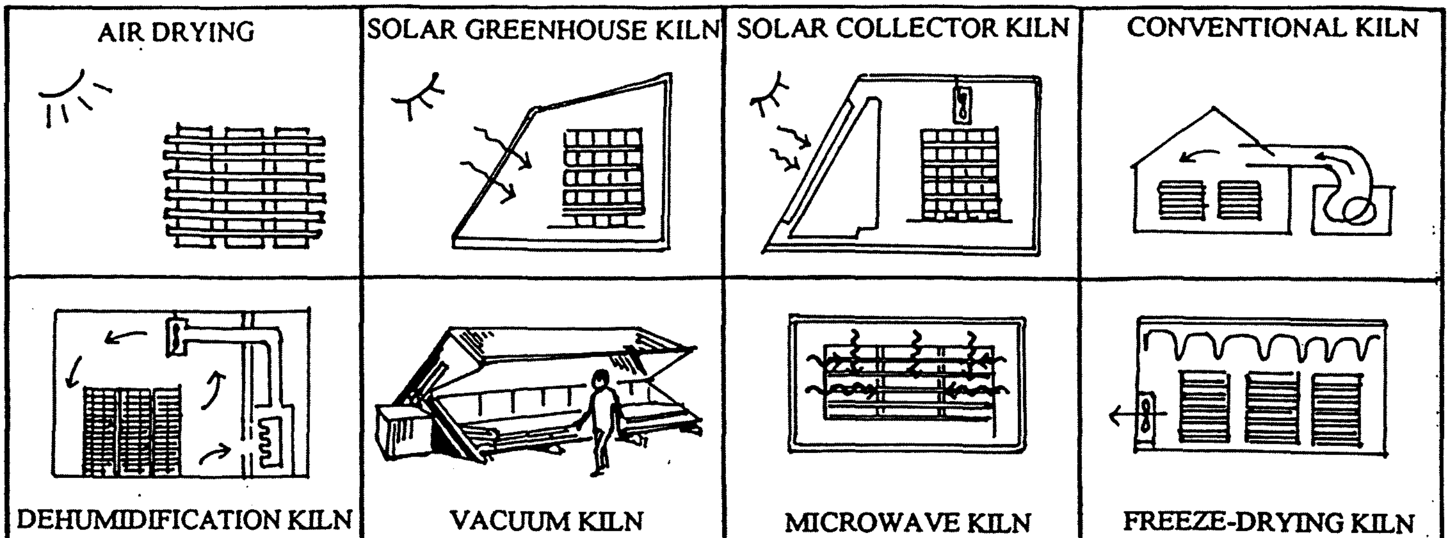


FIGURE 7: WOOD DRYING METHODS CURRENTLY IN USE OR UNDER DEVELOPMENT IN CANADA

OVERVIEW OF CONVENTIONAL, DEHUMIDIFICATION, AND SOLAR KILNS

An outline of the basic design features and operating principles of the more common kilns will be useful in trying to arrive at the best kiln choice for micro-sawing enterprises in this region.

Conventional Kilns: these kilns are usually meant to include large units that employ the generation of steam from various fuels. Steam radiators are used to heat the kiln chamber and steam may also be let out directly during conditioning stages or to raise the humidity and slow drying in initial stages. Humidity reduction is typically done by venting to the outside and bringing in fresh air. A heat exchanger may be used at the vents to try to reclaim some of the heat in the exhaust air. To reduce costs, some kilns are direct-fired and do not use steam boilers and radiators. Beside the provision of heat, conventional kilns have large fan systems that circulate the air through the lumber piles. The elaborate control systems allow for precise drying schedules and predictable results. The largest body of work on kiln schedules is geared to the conventional kilns. An experienced operator is necessary to control the various temperature and humidity functions of the kiln and local statutes may also require certified boiler operators. The kiln chambers can achieve temperatures of 180°F, which may be important if an export destination specifies lumber treated over 160°F for the control of certain organisms.

Conventional kilns have two major loading systems. A *package-loaded* kiln would hold between 25,000 and 90,000 board feet (1" thickness), and be loaded one lumber bundle at a time using a forklift. A *track-loaded* kiln has a rail and truck system that allows pre-loading of lumber outside the kiln chamber. Loads of 25,000 to 220,000 board feet are changed quickly by rolling out the dried lumber trucks and rolling in the green lumber.

From an energy standpoint, the continual venting of heated air is a major drain to the system, especially if the in-coming air is extremely cold. Heat exchangers can recover a portion of this loss. Older kiln structures typically have only moderate insulation and must be evaluated in the face of rising energy costs. Because drying times vary by species, it is difficult to give a typical drying time in conventional kilns. Suffice to say that these kilns are the industry standard and other kiln types may be said to be faster or slower than these types. Figure 8 shows a typical conventional kiln layout.

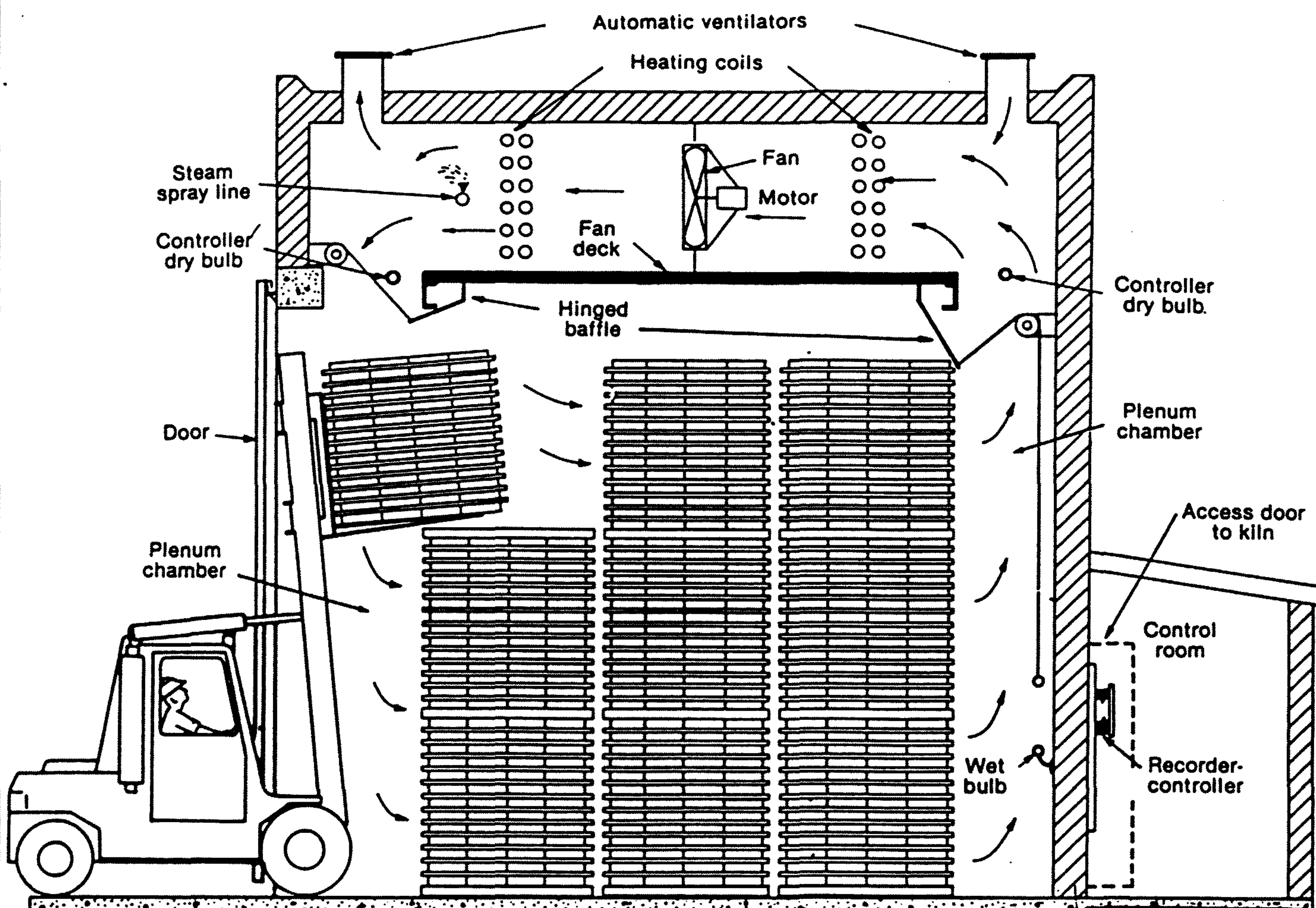
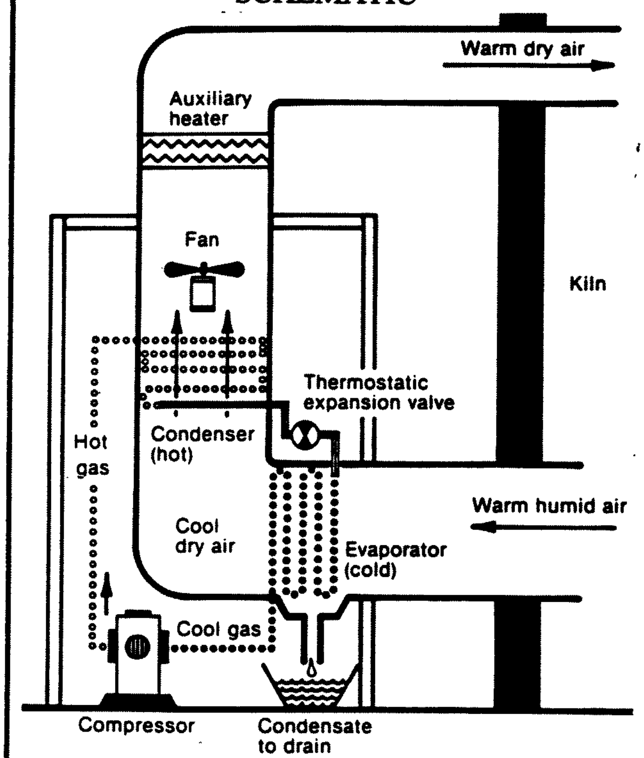
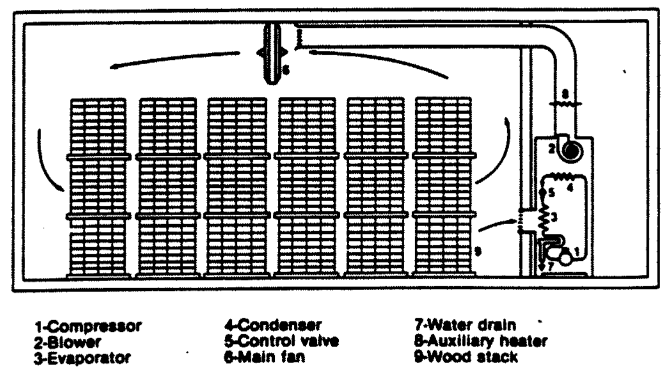


FIGURE 8: TYPICAL CONVENTIONAL KILN LAYOUT - BOILER UNIT NOT SHOWN

Dehumidification kilns: the advent of heat pumps and the desire to control rising energy costs led to this kiln type that has much in common with conventional kilns. The major difference is that a dehumidification kiln does not vent humid air but, rather, uses cooling coils to condense out the moisture and then recirculates the air. In this manner, the heat used to evaporate the water is regained. Also, the heat pump equipment can be located in the lumber chamber so that the mechanical losses in the compressor are added to the system as heat. These two features have meant large energy savings, especially in colder regions. The air circulation systems are similar to conventional kilns. Figure 9 shows a dehumidification kiln.

DEHUMIDIFICATION HEAT PUMP SCHEMATIC





DEHUMIDIFICATION KILN LAYOUT

FIGURE 9: DEHUMIDIFICATION KILNS

On larger kilns of this type, a small boiler may be added to assist in the warming of the load and to allow a steam conditioning period at the close of drying. Most dehumidification kilns use solely electricity, although multi-fuel supplementary heat could be added. The smaller units are designed only for heat from the pump and coil unit.

Dehumidification kilns range from 800 to 160,000 board foot capacity. The smaller units have been very useful for small woodworking businesses where the lumber volume could not justify a conventional kiln of at least 25,000 board feet. The upper limit for the chamber temperature is usually 120 F, 160 F on some units.

Dehumidification kilns are able to achieve higher overall efficiency than conventional kilns by avoiding the energy losses from venting heated air. However, this must be weighed against the dependence on electricity as the main energy source. One can expect longer drying times with dehumidification kilns as compared to conventional kilns because the maximum operating temperature is lower.

Solar kilns: the idea of concentrating or collecting the sun's heat directly for the purpose of lumber drying has been around for a long while, perhaps because it is such a logical extension of air drying. Two distinct types have evolved - greenhouse style and collector style. Greenhouse types for this region usually have three insulated walls and a glazed, sloping south wall and roof combined. The lumber is placed inside and fans provide the air circulation through the pile. Some units exhaust moist air for humidity control and others have provision to condense the moisture at the base of the glazing. Collector type solar kilns employ an insulated and isolated lumber chamber with fans, not unlike most other kiln types. Solar heated air is introduced to the chamber from a collector - typically a tall, south-facing, tilted wall. Humidity reduction may be incorporated by passing the moist air over a cooler surface below the chamber. The ability to add supplementary heat is one advantage of the collector type over the greenhouse type. A greenhouse type solar kiln is shown in Figure 10. Note that although the drawing shows a

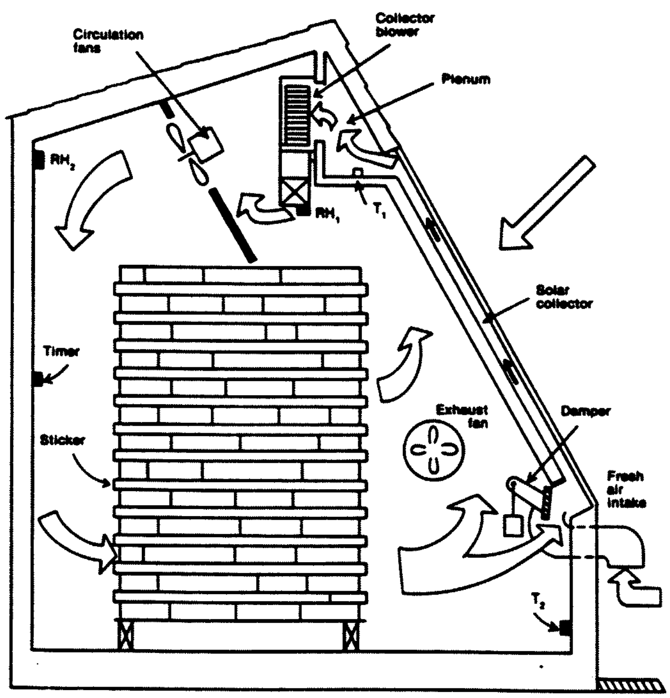


FIGURE 10: GREENHOUSE TYPE SOLAR KILN

'collector' on the south face, this kiln would be considered a greenhouse type for the purposes of this report because the glazing is not sufficiently isolated from the kiln chamber to allow for supplemental heat. Other researchers have described three or four classifications.

Solar kilns are unique in the provision of a *diurnal cycle* whereby the kiln becomes dormant through the night. Initially seen as a great disadvantage, testing has shown that a more stable wood results from this daily stress relief period. The upper limit for chamber temperature for solar kilns is about 130 F. The practical limit for kiln chambers is approximately 25,000 board feet. For larger capacities, additional collectors and chambers are built alongside. The discussion on solar kiln design outlines the reasons for these size requirements.

Close operator monitoring is not required for solar kilns and most units perform with a few simple on/off controllers. A thermostat engages the collector fans when warm air is available and a humidistat can adjust vents to the exterior as needed. Overall energy input with solar kilns is the lowest of all the kiln types - electricity is needed to run the fans only.

Unfortunately, there is insufficient data in the various studies to make a quick comparison of drying times in solar kilns with those in other kiln types. A discussion of the available information is given in the literature review section under DRYING TIMES.

CHOOSING A KILN TYPE: THE IMPORTANT VARIABLES

Even a cursory look at the major kiln types shows that each has its strengths and weaknesses. There is no way in which to rank order kilns because each type has a certain application and circumstance for which it is the best choice. What has happened over time, however, is that certain variables have become more important than they were in the past, and this can affect the decision as to which kiln is the best choice for now and for the future.

What follows is a discussion of the main variables affecting kiln choice. The specific application will dictate what priority each variable has, and unusual applications may even require consideration of additional aspects not listed.

Energy Source and Consumption

Energy requirement is an example of a variable that has been given more weight in recent times. One outcome of the 'energy crisis' of the mid-70's was that North America took stock of its energy consumption habits and began to think about alternative sources and reduced demands. In spite of temporary low energy prices on this continent, it is a certainty that energy will become more expensive as the number of people in the world increases and the amount of energy that each person demands also increases. Any industry that attempts to plan for the future will make choices that reduce its overall energy consumption as much as possible.

In choosing a kiln, then, the most energy efficient type is a wise choice. Where new kilns are being built, dehumidification units are sometimes chosen based on energy savings. Another option for new installations is the provision of a southern exposure and better insulation methods so that solar kilns can take advantage of much reduced energy dependence.

Beyond a concern for the *amount* of energy required, one should also consider the *geographical* limits imposed by the choice of *energy source*. For instance, it is of little value to propose a gas-fired kiln boiler for a rural area not served by gas lines. Certain types of energy favour certain types of settings. Solar applications favour rural areas over urban settings where adjacent buildings block the sun. Solar is also more suited to the Prairie region of Canada than it is to coastal or mountainous areas. Single phase electrical service is available to most areas but the pricing structure between rural and urban is not consistent. The price for electricity in some areas increases as consumption increases, while urban buyers pay less per unit as consumption increases. As well, three-phase power is unavailable in many non-urban areas. And, as noted above, natural gas, our cheapest energy source currently, is not universally available.

Drying Time and Predictability

The drying rate of a kiln is related to its complexity because it takes more controls and equipment to push wood to its limit without destroying it. In general terms, the faster you want to go, the more tricks and energy you'll need to succeed. Currently holding the speed record is vacuum drying, operating at many times the rate of conventional kilns. At the opposite end of the spectrum is air drying which is many times slower than conventional kilns. Each rate of production has its place.

Predictability is a variable in comparing solar kilns and other types because the weather can affect solar performance and introduce some uncertainty into the system in the short term. Other kiln types are closed systems that are unaffected by weather considerations.

It should be noted that even in times past when lumber took seven years to season in the air, the long lead time was only a problem initially. Assuming that lumber was set out to dry each year during the first six, then dry lumber was available every year thereafter. The first six years were definitely slow going, but an annual supply was available beginning in the seventh year due to staggered loading. Similarly, longer drying times can be circumvented to some degree by using multiple units and staggering the start dates. Thus, two kilns having 60 day cycles could yield a monthly supply of dry lumber.

Scale of Operation

Various kiln types suit various scales of operation. Dehumidificiation units span the greatest range, being appropriate for the hobbyist at 800 board feet per load up to the large scale sawmill at 160,000 board feet. Vacuum kilns are currently made in 2000 board foot units. Very small greenhouse type solar kilns are possible, but collector types would tend to be based on chambers of 10-25,000 board feet each due to the relationship between chamber height and collector height. (This is not a dictum, but rather a matter of convenience in construction - if kiln chambers are built side-by-side, then collector width is limited to the chamber width. If a safe stack height for lumber is 10 feet, then collector height is limited to perhaps 15 feet to avoid undue cost in enclosing the entire unit.)

In choosing kiln size, one needs to consider the volume of like species and like thickness that is typically ready to dry at one time. A large operation that dries one species in one thickness can operate efficiently with one large kiln. However, a small producer with a variety of species and sizes would be best served with a few small units. Two or more small kilns allows for the greatest flexibility in terms of starting drying immediately after sawing, staggering finish dates and handling a variety of species and thicknesses.

Operator Input

Kiln types that employ more elaborate equipment will tend to require more attention from an operator than those types that are simpler. As well, kilns which push wood to its limits will demand closer observation because a small error by the automatic controls can ruin an entire load. Solar kilns are generally thought to require the least operator input and can be left unattended for several days, if need be. Conventional and dehumidification units may require daily monitoring and adjustment as drying progresses.

Capital Cost and Operating Cost

The capital costs for conventional, dehumidification, and solar-collector types are roughly equal for the *chamber portion* of the kiln,(assuming the same lifespan for each case) since all three require a well insulated 'box' with loading doors and circulating fans. The cost differences will be seen in the heat producing and humidity reducing equipment. Figure 7 shows common kilns in order of complexity. As might be expected, this is also the order of cost, in general terms; for very large-scale operations, it could be argued that a conventional steam kiln is the least expensive of all choices. It must be borne in mind that a realistic capital cost for comparison purposes would need to take into account the annual production of the kiln rather than the size of each kiln charge.

Operating costs should reflect both the cost of the energy inputs and the maintenance costs of the component parts. Again, the mechanically simplest system will have the lowest maintenance costs. Solar kilns, then, offer the lowest energy cost and the lowest maintenance costs, with only a few fans to attend to. Costs will increase as one progresses from boilers (conventional) to heat pumps (dehumidification) to vacuum pumps (vacuum kilns).

In a proper assessment of all costs, the equation would look like:

$$\frac{\text{Capital cost} + \text{energy cost} + \text{maintenance cost} + \text{operator wages}}{\text{annual dried lumber production}}$$

AN APPROPRIATE KILN FOR RURAL MICRO-SAWING ENTERPRISES

At the outset, the reader was introduced to the reasons for drying lumber and some of the problems that typically arise in the process. An overview of kiln types provided a description of the equipment available for wood drying and a guide was given for choosing among the different types. It was noted also that the important choices regarding kilns centered around the specific application and location of the kiln operation.

To make a choice among the many drying options, then, it is necessary to clearly define the nature of these small-scale rural sawing businesses.

One of the difficulties in trying to pinpoint the details of a proposed business plan is that actual enterprises based upon the general idea may vary greatly. Indeed, one of the features of these enterprises is that they can take many forms and be pursued as full-time employment for a sawyer/kiln operator, or as supplementary income for farmers and landowners. And in a larger sense, there is great variety in the forest resource throughout central Canada. A small-scale sawyer in the Kenora, Ontario area has a completely different array of species and tree sizes than does his counterpart in Portage La Prairie, Manitoba, and different again than a sawyer in Prince Albert, Saskatchewan, or Hinton, Alberta.

Thus, any attempt to specify a business plan is necessarily only a general guideline or a set of ideas that would have to be adjusted to suit local conditions. Appendix B lays out a suggested business plan that could be adapted throughout this region.

What are the main points in the business plan that affect the choice of a suitable kiln?

Volume to be dried: 100,000 board feet per year
Sawmill Production: 4,000 board feet/week, March to October
Location: rural or remote
Energy Availability: solar, electricity (hydro- or diesel-generated,) (oil and propane available with some limitations)
Staffing Structure: owner/operator and crew, sawing ongoing, minimal kiln inputs desirable

Based on these requirements, is a solar kiln a suitable choice? In terms of yearly capacity, a kiln of 20-25,000 board foot size would need to handle 4 or 5 loads per year. If the kiln is idle during the 3 months of lowest solar radiation, November, December and January, then there remains 275 days of kiln operation per annum. This would allow for 5 charges at 55 days each, or 4 cycles of 69 days duration. The literature review to follow can suggest typical drying cycles based on experience in existing kilns, but as an initial estimate, 55 to 70 day cycles appear feasible.

How does a 20,000 board foot unit compliment the sawmill production? A solar kiln of this size could have two chambers of 10,000 board feet each. If a typical cycle for the kiln is 9 to 10 weeks, and the chamber loading was staggered by 4-5 weeks, then the sawmill would produce faster than the kiln. The kiln is accepting 10,000 board feet every 4 1/2 weeks, and the sawmill is producing 10,000 board feet every 2 1/2 weeks. There would always be a load of lumber ready to dry - some air drying could occur during the waiting period. On a yearly basis, the entire sawmill production would go through the kiln, but during the sawing season the sawmill would get ahead of the kiln.

For rural and remote settings where electrical service can be more expensive than urban areas, the solar kiln offers the least possible electrical demand of any drying system - only the circulating fans require electricity. This should be a real advantage in maintaining low operating costs now and in the future. With collector type kilns, there is the option of adding auxiliary heat in order to boost production during adverse weather or the colder portions of the year. A waste wood burner would supply extra heat to the system very economically.

In terms of capital investment, a collector type solar kiln is the least expensive option that offers a long operating season and reasonable yearly production. It also offers the least expensive long term maintenance costs because the fans and controls are readily available and easily serviced.

For use in a business where the sawyer may be sawing at sites away from the kiln, the solar kiln has the advantage of not requiring daily monitoring or adjustment. The kiln can function several days at a time without an operator. This reduces the overall labour cost of kiln operation.

For many reasons, a collector type solar kiln seems to fit well into the model for small-scale rural sawmill operations. Certainly almost any of the other kiln types could be operated in the same setting, but each one represents a move toward higher initial cost, higher operating cost, higher maintenance cost, more operator input, and greater energy demands. The benefit of choosing other kiln types would be higher production. However, if a solar kiln as described can keep pace with the bandsaw mill, and the whole yearly cycle represents a reasonable workload for an owner/operator and small crew, then what advantage is a faster kiln? The same arguments that favour the 'scaling up' of resource based industries seem to lead back to a paradigm of rural harvesting and urban processing. It is the overall purpose of this work to create small-scale sawing businesses firmly rooted near the resource.

If a solar kiln is to be the best choice of drying system for this application, what can be learned from the literature on kilns built to date? Are there similar applications that lend support to the assumptions made here about production, operation, and cost? And , as to the underlying presumption about all viable kiln systems, do solar kilns produce a high quality dried product?

LITERATURE REVIEW - SOLAR LUMBER KILNS

Most undertakings that launch into a new area have a basis in the research that precedes them. Even projects that include truly novel features and ideas benefit from a search of all the related work already done. Solar lumber kilns have been appearing in the research literature for almost 30 years now, and were certainly being built on a less formal basis for many years before that.

Some of the more active research grew out of work on the more general topic of low temperature drying. It would seem that an increasing demand for kiln dried construction lumber during the 60's fostered work on alternatives to air drying. It was uneconomical to load softwoods directly into the kiln without some pre-drying, but the slowness and seasonal variations in air drying forced producers to have a large inventory to bridge the time lag from sawn to kiln-ready. Thus, we find work by Cech and Huffman (1968a,b) on fan-assisted outdoor drying of spruce and balsam fir, and low temperature kiln trials. Early solar kiln work is therefore aimed at pre-drying ahead of conventional kilns, and the results are often given in terms of how much improvement was obtained over air drying. Some early work found the lower limit of moisture content to be about 20%, which would reinforce the idea that solar kilns were suitable as pre-dryers, but not a complete kiln system in themselves, (Uncredited work, 1976?, reported as Dryer #22, Princeton, West Virgina, Wengert and Oliveira, 1983).

Solar lumber kiln work advanced very quickly in the late 70's as a response to the 'energy crisis' of the early seventies. Industries that relied on inexpensive oil, and there were few that did not, were very interested in alternative energy sources. In the lumber industry, solar heating was a logical choice for kiln operations. Oddly enough, the bulk of the work in the literature describes kilns that were proposed for use in developing countries, typically in latitudes under 30'. All of the reasons for this focus are unclear, but the research appears to have been related to our efforts to provide aid to less developed countries, (Oliveira, pers. comm.).

The book, Solar Heated, Lumber Dry Kiln Designs, (Wengert and Oliveira, 1983) provides an excellent summary of 31 kilns worldwide. Most are experimental in scale, a few are large capacity working kilns. The book's introductory notes give a good overview of solar kiln design and operational knowledge up to that time. With the publishing of such a catalogue of effort around the globe, one might assume that the research continued in earnest through the 80's, but in fact, the entire topic of solar lumber kilns seems to have disappeared. This might be attributed to governments funding other endeavours instead, but why would the lumber industry itself not follow up on any of the initiatives set in motion with government support? We find virtually no reporting in the industry journals of successful solar kilns in operation. Ocassionally a newspaper article will feature a small sawmill that has added solar panels to a shed, but there are virtually no full-scale solar kilns dating back to the early 80's from which some reliable longitudinal data could be found.

Despite the inactivity at research centres which previously led the field, a full-scale solar kiln was built near Prince Albert, Saskatchewan in 1987. It stands as Canada's only work in the field since 1981. This kiln is still in use on a commercial scale, and the data gathered in its first 18 months of operation are included in this review. A copy of the report appears as Appendix C.

Activity has again taken an upswing, although it is now centred on the Canadian Prairies, in Australia, and South Africa. The focus of the work is on offering an economical and simple kiln to produce high quality dried lumber for small scale mills in rural areas. It is hoped that the work will have long term application in keeping with the growing recognition that small enterprises are economically important and that rural areas need viable industries to halt their depopulation.

EXAMINING THE RESEARCH TO DATE

As noted earlier, the literature on solar kilns covers a wide variety of types of kilns and locations. Also, most of the work is more than ten years old, and covers only a few full-scale units (as opposed to very small test units). And finally, none of the papers offer data that spans more than two years. A chronological survey of this body of work would not yield a clear picture of the direction that solar kilns are headed. The only bright spot in the field is the large unit in Saskatchewan (Bell and Ellis, 1988) which is, fortunately, an excellent model for this report. I have therefore opted to survey the literature topic by topic. To present the information relevant to our task, a discussion will be given on: 1) solar kiln types; 2) collectors and ratios; 3) diurnal cycling; 4) supplemental heat; 5) drying times; and 6) drying costs.

SOLAR KILN TYPES

The simplest division of solar lumber kilns would show two sorts:

Greenhouse type - kilns in which the glazing forms a portion of the lumber chamber.

Collector type - kilns in which the solar collection device is isolated from the lumber chamber.

Others have made up to four groupings of kiln types, but the important distinction in this paper concerns the ability to add supplemental heat. One would not normally attempt to warm a greenhouse type kiln using electricity, wood, or fossil fuels because the glazing would lose heat too rapidly. A collector type kiln can accept supplemental heat because the solar collection device is isolated from the lumber chamber. Figure 11 show examples of both types.

Chen (1979) notes that the majority of the solar kilns built in the last 20 years have been greenhouse types and of low efficiency. Wengert (1971) reports a 1200 board foot kiln making use of only 15% of the available solar energy. Using an aluminum can collector, Chen was able to obtain 60 to 65% efficiency in the collector and 67 to 90% efficiency in a kiln in southern Illinois (38 N). This is a marked improvement over earlier greenhouse type kilns. Even so, this collector type kiln was quite limited in its application. The researcher notes that pre-drying the lumber down to 60% moisture content and limiting load size to 2-3,000 board feet would be appropriate. Further, final moisture content will be 15%, and best performance will be summer and early fall. One should avoid winter use; drying times are roughly 7 times longer. This same kiln was later modified to include dehumidification and steam conditioning equipment (Chen, Helmer, Rosen and Barton, 1981). Good results were obtained, but the contribution of the solar collector dropped to an average of 21% of the total energy demand.

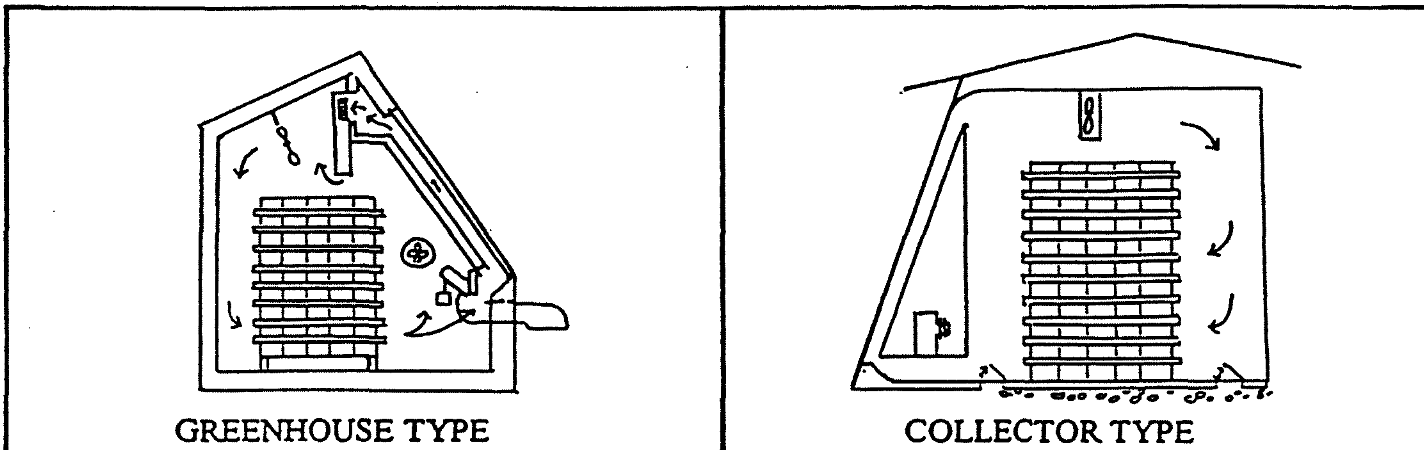


FIGURE 11: TWO TYPES OF SOLAR KILNS

Research at Thunder Bay, Ontario (48°N) by Yang (1979) noted again that the bulk of the work on kilns was in warmer climates (Uganda, Philippines, Australia, etc.) and used the greenhouse model. His approach was to test a semi-greenhouse unit at a higher latitude. *Semi-greenhouse* is taken to indicate those units which restrict glazing to the south wall or south wall and sloped roof. With a capacity of 500 board feet, his experimental unit achieved a 10% final moisture content in softwood during a summer test run of 12 days. Winter runs were about 8 times longer. Yang concluded that heat loss through the glazing was excessive and a second layer of glazing would be helpful. Solar drying at high latitudes was considered feasible, but the winter season should be omitted. Solar radiation was noted to be greater at this latitude than lower latitudes during the summer. In a larger kiln built two years later, triple glazing was used, capacity rose to 100,000 board feet, back-up wood heat and rock storage were added. The semi-greenhouse method was retained (reported in Wengert and Oliveira, 1983).

In the largest compilation of solar kiln work to date, Wengert and Oliveira (1983) report on 31 kilns from around the world. In the introductory notes, they outline three kiln types. *Greenhouse* kilns are inexpensive and simple choices for warm climates. They offer slower and cooler operation than other solar kiln types, and leave relatively high moisture content in the lumber. *Semi-greenhouse* kilns limit glazing to the south roof and/or wall. They tend to produce higher temperatures and faster drying with lower final moisture content compared to full greenhouse types. *Opaque wall* kilns have isolated collectors and give much reduced nighttime and poor weather heat loss. In addition to the ability to add auxiliary heat, this type can achieve very low final moisture content. In general terms, the greenhouse units are located in lower latitudes with a mixture of semi-greenhouse and opaque wall units in the higher latitudes.

Tschernitz (1986) provides an extensive computer analysis of solar energy applications for wood drying. Rather than testing actual kilns, this paper pulls together climatic data, fuel costs, material costs, drying times and solar collector performance so that an economic analysis can be given for a variety of scenarios in many locations in the United States. Rather than modelling greenhouse versus collector types, the work differentiates between direct and indirect collection and insulated or uninsulated collection, in order to cover a wide variety of cases. It is not clear whether a fully isolated collector type kiln would follow the data given or not. In his conclusions, Tschernitz states that supplemental energy is necessary to maintain drying times in all seasons and that the solar surfaces should be isolated from the dryer at night and during times of low solar influx. Further recommendations state that: the choice of solar glazing is critical, the winter months in the north are not practical for solar drying, the choice of collector surface be limited to south wall or south wall and sloping roof, and the provision must be made for a conditioning or stress relief cycle at the close of drying. In spite of these provisos, he believes that even a home-built unit of a thousand board foot capacity would be useful for non-commercial operators for at least 9 months of the year without supplemental heat in the northern tier of states.

The kiln constructed near Prince Albert, Saskatchewan (Halland, Ellis and Bell, 1987) followed more the lines of a demonstration project than a research work. However, proper monitoring and analysis were completed based on eighteen months of operation (Ellis and Bell, 1989). The 40,000 board foot unit has two lumber chambers and is a collector type kiln, as research up to that time would have suggested was best for higher latitudes (54 N). A high performance solar collector was used (see Collectors and Ratios) to form an isolated south wall. Assuming a 200 day operating season, the projected drying times for economic viability were well within actual performance. For pine and aspen (botanical names not given in the report) drying times averaging 30 days were anticipated following minor modifications. The addition of radiant in-slab supplementary heat significantly extended the useful annual cycle for the kiln.

About 1990, a commercial kit-form solar kiln came onto the market. It is a semi-greenhouse style by Wengert and Oliveira's definition - three walls are insulated and the south sloping roof is glazed. Among the features are two layers of glazing film inflated by a fan; moist air is blown into the inflated cavity and drops its moisture at the base of the outer glazing. The entire glazed wall/roof opens for loading. Sizes range from 750 to 7200 board foot capacity. A number of units are operational in eastern Canada. No independent research covering these kilns has yet been distributed, nor have they appeared in the industry literature. Operational experience with these units will emerge over the next few years. However, lacking any independent evaluation or testing, no data are available beyond the manufacturer's marketing information.

A doctoral thesis and subsequent research by Steinmann (1989,1992) comprise some of the most recent activity on solar lumber kilns. Based in South Africa, the work focuses on collector type kilns only and pursues the suitability of various collector to lumber ratios and the usefulness of tracking devices to allow the collectors to follow the sun. Of interest to this discussion is the lack of mention of greenhouse kilns.

In summary, from the material available, it would seem that collector type solar kilns offer the best chance of success for the Prairie region. The higher temperatures and lower final moisture contents possible in this model are attractive features. Many researchers have recognized the need for supplemental heat to extend the useful annual kiln season and cover long periods of adverse weather. The lumber chamber needs to be well insulated and losses to the collector minimized if supplemental heat is to be retained in our cold climate. This is obviously best done in a collector type unit rather than a greenhouse type. The well-insulated chamber in a collector type kiln also offers the option of adding dehumidification and/or steam in the event that these are warranted. Tschernitz's computer generated analysis showing that even the simplest greenhouse kiln would give 9 months of service per year in the northern states is strong support for solar lumber drying in general. Moving north of his study area, increasing volumes to 20,000 board feet per load, and operating commercially, it would only be wise to opt for the most versatile solar kiln available.

COLLECTORS AND RATIOS

Early in the design process for a solar lumber kiln, the question arises: how big does the collector need to be for each thousand board feet of lumber in the kiln? (Thousand board feet is typically written - Mbf). In a larger sense, the real question is: how much of the sun's energy is available and how much energy is needed to dry lumber?

As one studies solar design concepts, it becomes clear that solar energy is unlike all other energy sources. Man has typically manipulated fossil fuels, natural fuels, electricity, and nuclear energy to suit our applications and we are accustomed to energy sources that are easily measured, of predictable magnitude and intensity, and readily controlled. Solar energy is none of these. How, then, can we determine the suitability of solar energy for lumber drying?

Despite our unease with forces we cannot control, it is still possible to make a general assessment of the available solar energy. For the Prairie region of Canada, the annual average available solar energy is 1000 to 1200 Btu per square foot of horizontal area per day. Note the qualification -'annual average'. From month to month, the variation can be great. During winter months, the available solar energy may be as little as 300 Btu/sq.ft/day or less, and during summer months, 2000 or more! Beyond seasonal variations, there are day-to-day fluctuations as atmospheric conditions affect the solar energy that reaches the earth's surface. Bearing in mind the tremendous variations over time, let us proceed with the figure of 1100 Btu/sq.ft/day for estimating purposes.

An estimate of the energy needed to dry wood can be fairly simply arrived at by calculating the amount of water to be removed per day. A species like bur oak could tolerate 2.5% moisture loss per day without severe defect (Wengert, 1990). A thousand board feet of lumber losing 2.5% moisture results in 70 lbs of water. The heat needed to evaporate 70 lbs of water is 70,000 Btu. Therefore, 70,000 Btu per day would require 64 square feet of collector surface. A rough ratio of collector size to lumber is then 64 square feet of collector per thousand board feet of lumber.

Unfortunately, the calculation of the energy used in a lumber kiln must include far more than the energy of evaporation. As noted earlier, experience shows that conventional drying requires approximately 2 to 2-1/2 times the energy of evaporation. Account must be taken of the heat needed to raise the temperature of the lumber and the kiln itself, plus the losses through the kiln surfaces to the outside, plus the losses by air leakage and, finally, the losses by exhausting moist air. And as to the input side of the energy equation, in the above solar energy calculation we have made the assumption that the collector is 100% successful at capturing and converting the solar radiation that comes to it. To accurately predict the performance of a solar collector lumber kiln is indeed complex! Our initial calculation really only tells us that a solar kiln is within the realm of possibility.

Going through the literature to compare the results of one study with the next, there is the ongoing assumption that all collectors are equal, and the differences in results are due to collector size, or possibly the location of the study, or the time of year. In fact, there is great diversity among collectors, and they represent a complex body of endeavour on their own. They may have 1, 2, or 3 layers of glazing, a dozen different glazing types, a variety of colours and materials for the absorber plates, air spaces from 1/2 to 4 inches, air flow on one or two surfaces, additional fins, etc., etc.

A similar assumption is made regarding the suitability of the operating details of any given kiln. The ability of a kiln to efficiently dry lumber is related to the velocity of the circulating air, the relative humidity of the air, the ability to monitor and adjust conditions as the lumber dries, and so-on.

Given the number and complexity of the variables at work in a lumber drying situation, it is very difficult to draw conclusions from the various works that have been done over the years. For instance, a comparison of the kilns in Wengert and Oliveira's compilation (1983) shows a range of 20 to 260 square feet of collector per Mbf. Without some common procedures for kiln operation, it is impossible to judge how performance might be related to the collector size to lumber ratio. As if there was not sufficient uncertainty already, Tschernitz (1986) reports that computer modelling shows large kilns to have half the energy demand per lumber unit as small kilns. The small demonstration kilns typically used for study, therefore, could have an error of 100% compared to a full scale version.

Chen (1979) is among very few studies which attempted to assess collector efficiency as part of the results. The recent work by Steinmann (1992) centred around the impact of collector size on kiln performance and the value of collector tracking, using a laboratory simulation. This is perhaps the only study available in which collector size is varied while other aspects are held constant. Collector areas of 50 to150 square feet per Mbf were tested. Steinmann concludes that a tripling of collector size yielded a lowering of final moisture content of only 1 percentage point. The same tripling of size produced only a 21% decrease in drying time, and a 1.4 C rise in average kiln temperature. The actual Stellenbosch kiln was found to achieve 1% per day moisture reduction per Mbf for each 25 square feet of collector. Steinmann suggests that the optimum collector size lies between 50 and 150 square feet per Mbf, but more work is needed to pinpoint it.

The collector used by Halland, Ellis and Bell (1987) underwent ASHRAE testing prior to installation. The ability of the collector to gather solar radiation was shown to be 200

Btu per square foot per hour. This is a high rating compared to other collectors. The test procedure did not allow for the *reflected* radiation to be included in the results, however, in the kiln application, provision is made for a reflected gain from the area in front of the collector to augment performance. This typically increases incoming radiation by 85% and boosts the collector's performance by 30-40%. The full scale demonstration kiln has 720 square feet of collector surface and a lumber capacity of 40 Mbf; a ratio of 18 square feet per Mbf.

Subsequent work by Ellis (1990) using the same collector for grain drying applications suggests that optimum drying is achieved with a 20 F temperature rise across the collector. The temperature rise results in a sufficiently low relative humidity to facilitate drying.

What, then, can be concluded from the literature regarding the ratio of collector size and lumber capacity? Because there is no 'standard' collector, there is no way to make comparisons within the huge variations found in the studies. One unit of a very good collector may well be equal to 4 units of another collector. Beyond the inequality of collectors, there is the variation in air velocity and humidity, and a further question as to the energy demands of experimental scale versus full scale.

Perhaps the strongest indication as to appropriate collector to kiln capacity ratio is given by Ellis and Bell (1989) who show 18 months of results with a full-scale solar kiln in central Saskatchewan. A ratio of 18 square feet of high efficiency collector per thousand board feet of lumber capacity yielded reasonable drying times.

In addition to collector-to-lumber ratio and thus, collector size, thought needs to be given to the angle of collector orientation. At least 2 factors are at play here. The first is that the desired season of operation affects the choice of collector angle. A more nearly vertical orientation will improve late fall, winter, and early spring performance (when the sun is low in the sky) but sacrifice some summer performance. An orientation equal to the location's latitude will favour late spring, summer and early fall performance (when the sun is high in the sky.) A second factor is the collector's design - how well does it accept incoming radiation at angles far away from 90 ?

The collectors used by Ellis and Bell (1989) were oriented at 75 or 15 off vertical. It should be noted that the foreground reflector is an important design element with this particular collector as its internal absorber faces are oriented to accept radiation from many angles.

DIURNAL CYCLING

One of the early concerns with solar lumber kilns was the fact that they would not be active during the night. Conventional kilns functioned around the clock on a precise schedule - wouldn't a kiln that only worked during daylight hours be very slow? Yang (1978) incorporated a gravel bed in his greenhouse kiln in order to offer some heat storage capacity, but other kiln research made no mention of the diurnal nature of this solar application (Chen, 1979). Yang's second kiln (1981), a full scale unit of large capacity, had a significant rock storage component and also back-up wood heat.

Parallel work in Australia began with Gough (1981) who made no effort to counteract the cycling, but his successors, Palmer and Kleinschmidt (1992), took special note of the 'diurnal performance' when the same kiln was reglazed. They found this particularly helpful with larger section timbers and species prone to checking.

Chen's kiln (1979) probably produced a satisfactory dried wood due in part to the daily cycling, but the benefit was unnoticed. Two years later, when the same kiln was fitted with dehumidification equipment to supplement operation (Chen, Helmer, Rosen, Barton, 1981), the researchers found the need to add steam conditioning equipment as well. One might suppose that the supplemental equipment permitted the kiln to be run on a more conventional schedule, and the beneficial nightly stress relief period was lost.

Diurnal cycling soon came to be viewed as an advantage and Wengert and Oliveira (1983) describe a nightly stress relaxation period when humidities in the kiln rise sharply. Warning is given to avoid supplemental heat so as to maintain this solar kiln advantage. In Tschernitz's computer analysis, supplemental heat is assumed to be essential, and we again see the addition of stress relief provisions.

Ellis and Bell (1989) emphasize the contribution of the diurnal cycle towards eliminating case hardening in particular.

Experience in Australia has suggested that solar kilns were out-performing conventional kilns with regard to stress relief with hardwoods. Dr. T. Langrish has just undertaken a 3-year study to design and construct a conventional kiln that will simulate the diurnal schedule of solar kilns (Timber Trades Journal, August 1993).

The nighttime stress relief period is now recognized as a benefit of solar kilns and an important element of work with difficult species like oak. Designers are careful when adding supplemental features that the diurnal effect is not inadvertently lost.

SUPPLEMENTAL HEAT

An obvious solution to decreasing solar radiation as winter approached was to add supplemental heat to the kiln, and this was especially attractive for collector type kilns because the insulated chamber would respond quite well to the added energy . Even greenhouse type kilns were built with back-up heat: Yang's first unit (1978) has no extra heat provision, but the full-scale unit (1981) has generous waste wood burners backing the north chamber wall. As previously noted, Chen, Helmer, Rosen and Barton (1981) boosted production with not only heat but dehumidification as well. Part of the objective was to raise kiln temperature to 160 F from roughly 120 F. Wengert and Oliveira (1983) recommend against supplemental heat in order to preserve the stress relief cycle.

In-slab radiant heat connected to a small water heater was added to the Saskatchewan kiln (Halland, Ellis and Bell, 1987) in 1993. Electricity was used in this case, but other fuels could serve as well.

Supplemental heat is a worthwhile addition to a collector type solar kiln provided that the intended uses are borne in mind as operational guidelines. The main intention is to extend the season in the spring and fall, but not to run during the 3 worst winter months. Additionally, it may be helpful in getting new loads underway quickly during a period when the rapid evaporation and warming of the lumber piles are depressing kiln temperatures. A long spell of adverse weather might also present a situation helped by supplemental heat. It is not the intent to lower final moisture content levels, because a collector type kiln is capable of very low values on its own. Finally, caution should be taken not to undermine the diurnal cyle and introduce internal stresses into the lumber (Ellis, pers. comm. 1994).

DRYING TIMES

Early in their development, solar kilns were seen as an improvement over air drying and comparisons were made, such as, solar drying was twice as fast as air drying with less degrade found. As experience with solar drying grew, researchers began to draw comparisons with conventional kiln drying - it was apparent that solar kilns could achieve more than just an improvement over air drying.

In planning for a kiln on a commercial basis, it is important to be able to estimate typical drying times because it dictates the size or number of kilns required to handle the annual production. Decades of experience with conventional kilns has yielded a reliable set of drying schedules, and variations on the conventional kilns, like dehumidification units, make use of the same schedules slightly modified. No such information is currently available for solar kilns.

Trying to deduce such information from the various studies since the mid-70's runs into the same problem encountered in trying to outline collector sizing - there is very little data on a very large topic. The area of solar lumber drying includes at least two separate bodies of knowledge: the gathering of solar energy and the physics of lumber drying. Each is a complex topic on its own. It is little wonder that so much variety exists in the research on solar lumber drying. The active research is sufficiently recent that very few studies focus on one variable and hold the others constant in a manner that would allow comparisons from one work to the next. Until there are several full scale operating solar kilns in this region, we will not see the kind of data needed to fine-tune the science of solar lumber drying.

References to drying times do occur in the literature, of course, but in total they cannot predict much about the results we could expect for our situation. Steinmann (1992) reports drying *pinus radiata* from 100% to 12% moisture content in 15-19 days, depending upon collector size. This tree is not native to Canada, but Canadian pines typically dry in conventional kilns in 3-10 days. Simulating summer season kiln conditions, his experience suggests that solar drying will require roughly triple the time of conventional drying. Gough (1981) found solar drying times to be 2-3 times longer than conventional methods in Australia.

In preparing an economic analysis of the Saskatchewan kiln, Ellis and Bell (1989) took an unusual tack on the topic of drying times. With only 5 kiln loads monitored over 18 months, and the inevitable modifications that accompany start-up with new equipment, they chose instead to work backwards from a profitable operation scenario to determine what drying times were necessary. Even with only two loads per year, the kiln was financially viable with hardwoods. This would allow 100 days per load in a 200 day operating year. Actual experience suggested that 45 days was a reasonable average with hardwoods. Softwoods gave a different picture, due to their lower value: 55 day cycles to achieve financial viability, with experience showing that 30 day cycles were most likely. How does this compare to conventional kiln drying? White birch, being a hardwood of moderate drying difficulty - not as easily dried as basswood, but not as troublesome as oak, would typically dry in 5 days. Pine would dry in 3-10 days. The solar kiln results are showing an average of 5 to 6 times the conventional rate.

In estimating drying times, the conclusions of several researchers should be heeded: solar drying is most suitable for small-scale operations that have flexibility and non-critical supply schedules (Gough, Yang, Ellis and Bell). Until a larger body of operating knowledge can be gathered, a conservative estimate of drying times within a conservative annual operating season is recommended. December and January can be omitted, as a minimum. Drying time calculations which err on the long side plus the option of supplemental heat will guarantee that the kiln runs an extra load rather than falling short at year end.

DRYING COSTS

The total cost of kiln drying lumber has at least three components: the cost of labour to load, unload, and monitor the kiln, the cost of all energy inputs (fans, heat), and the value of lumber lost to degrade. Of course, amortization of the capital cost of the kiln would also be reflected in the total cost of drying. Ellis and Bell (1989) address this in their economic analysis of the Saskatchewan kiln - see Appendix C for further detail. In the business plan for rural micro-sawing enterprises, capital amortization is shown for all of the equipment. For the sake of brevity, related costs such as insurance are not included - they would either be constant across various kiln drying options or of a magnitude that would not greatly impact the overall costs.

The work by Ellis and Bell (1989) is the only study which details costs in a manner that allows comparison in our region. Experimental kilns are of such a scale that loading labour is not comparable to full-scale kilns, and international energy and labour costs are not relevant to costs here in Canada.

The cost of handling 40 Mbf for the Saskatchewan kiln is calculated as 4 hours loading and 4 hours unloading times $70/hr for operator and machine: $560 / 40 Mbf or $14 per Mbf. This is a generous estimate - a more realistic estimate might be $20/hr for the operator and $20/hr for the machine since a loader would likely be on-site for many other tasks besides loading the kiln. At $40/hr for man and machine, loading costs would be $8 per M. As to monitoring, one could allow 1/2 hour per day to simply check fan motors and controllers, and monitor kiln samples At $20/hr and 33 day cycles, this adds just over $8, just over $16 for 66 day cycles. A total labour input cost is between $16 and $24 per thousand board feet.

The energy cost is solely fans; some run only when the collector is generating heat and others run continuously to circulate air within the kiln. Using a conversion factor of 1hp = 0.745 kW, the fan loading is:

2 - 1.42 kW collector fans @ 6.25 hr/day = 17.75 kW
2 - 0.19 kW ventilation fans @ 24 hr/day = 9.12 kW 50.87kW / day
4 - 0.25 kW circulation fans @ 24 hr/day = 24.00 kW

(Experience with the Saskatchewan kiln showed a positive benfit to running the circulating fans 24 hours per day.)

This electrical load amounted to $3.02 per day, representing an energy cost of 6 cents per kilowatt hour. For 33 day cycles, the energy cost would be 33 X $3.02 divided by 40 Mbf or $2.52 / Mbf. The cost for 66 day cycles is then $5.04 / Mbf.

The value of lumber lost to degrade varies with the market conditions, so it is not possible to assign a value here. Suffice to say that the literature consistently reports solar dried lumber quality on a par with or better than conventionally dried lumber. Lumber degrade, then, will either be lower than or consistent with other drying options. (A minmum loss of 3-4% of lumber value may be expected with softwoods, more with hardwoods.)

Energy plus labour costs can be estimated as:

electricity - 42 kW to 84 kW X .06 / kW = $2.52 to $5.04 / Mbf
labour/loader - $8 / Mbf + ($8.25 to $16.50 / Mbf) =$16.25 to $24.50 / M

Estimated cost per thousand board feet: $18.80 to $29.50

A SOLAR KILN DESIGN FOR RURAL MICRO-SAWING ENTERPRISES

What type of kiln fits the needs of small-scale sawmills located close to the resource? What capacity would match the bandsaw mill's production? And what features and options should the kiln incorporate?

If the kiln requirements from the business plan are compared with the common lessons that appeared in some of the research on solar lumber kilns, an appropriate design should emerge. Before outlining a design, let us review the recommendations that have arisen from the foregoing discussion. For this region, a collector type solar kiln offers the advantages of a longer useful season and ability to accommodate supplementary heat if necessary. The business plan calls for yearly production of 100,000 board feet. If the three worst months of winter (in terms of solar applications), November, December and January, are left out as several researchers have suggested, the useful kiln season is about 275 days. Using a conservative estimate of 55 day cycles on average, then a kiln of 20,000 board foot capacity is needed. Given the long cycles, it is advisable to split the kiln in half and have two chambers of 10,000 board feet each. With staggered starts, a kiln charge should be ready each month except the first.

Figure 12 shows a kiln design based on the above suggestions. What assumptions were made in determining these building dimensions? The logical starting point in kiln planning is the lumber itself. In this case, each chamber is required to hold 10,000 board feet. To fit an insulated box around that lumber volume, one would ask what the bundle size is and how the bundles will be stacked. For a mobile sawmill business, I have assumed that much of the lumber will be cut away from the kiln and trucked in. A convenient bundle width for green lumber is 32 inches - three bundles fit across a truck deck. (Also, tractor mounted front end loaders often lack the power to handle 48 inch wide bundles that forklifts commonly accept. Green lumber is surprisingly heavy and smaller bundles are simply easier to manage.) Sizing the chamber involves some estimation of the typical board lengths that will be handled. In this kiln, allowance is made for 16 feet of length, typically 2 eight foot bundles. (In practise, unused spaces in the kiln are blocked in order to force air through, and not around, the lumber pile.) Four bundles across the kiln by 16 feet long yields 170 board feet per layer of 4/4 (1 inch) lumber. Each layer occupies the thickness of the board (1-1/8 inch) plus the sticker (3/4 inch) = 1-7/8 inch. A 10,000 board foot capacity chamber with 170 board feet per layer will require 59 layers. At 1-7/8 inch, 59 layers will be close to 9 foot, 3 inches. Including some forklift spacers, the stacked bundles will probably reach 10 foot, 6 inches. In determining how large the bundles will be and how wide and high they will be stacked, the reader is cautioned to keep safety in mind - lumber is very heavy even in the dry state and a lumber stack that is too high, too narrow, stacked poorly, or beyond the operator's skills and equipment will be extremely dangerous. No recommendation as to safe sizes and heights for stacked lumber is intended; the intention is to show how one would go about calculating a suitable chamber size.

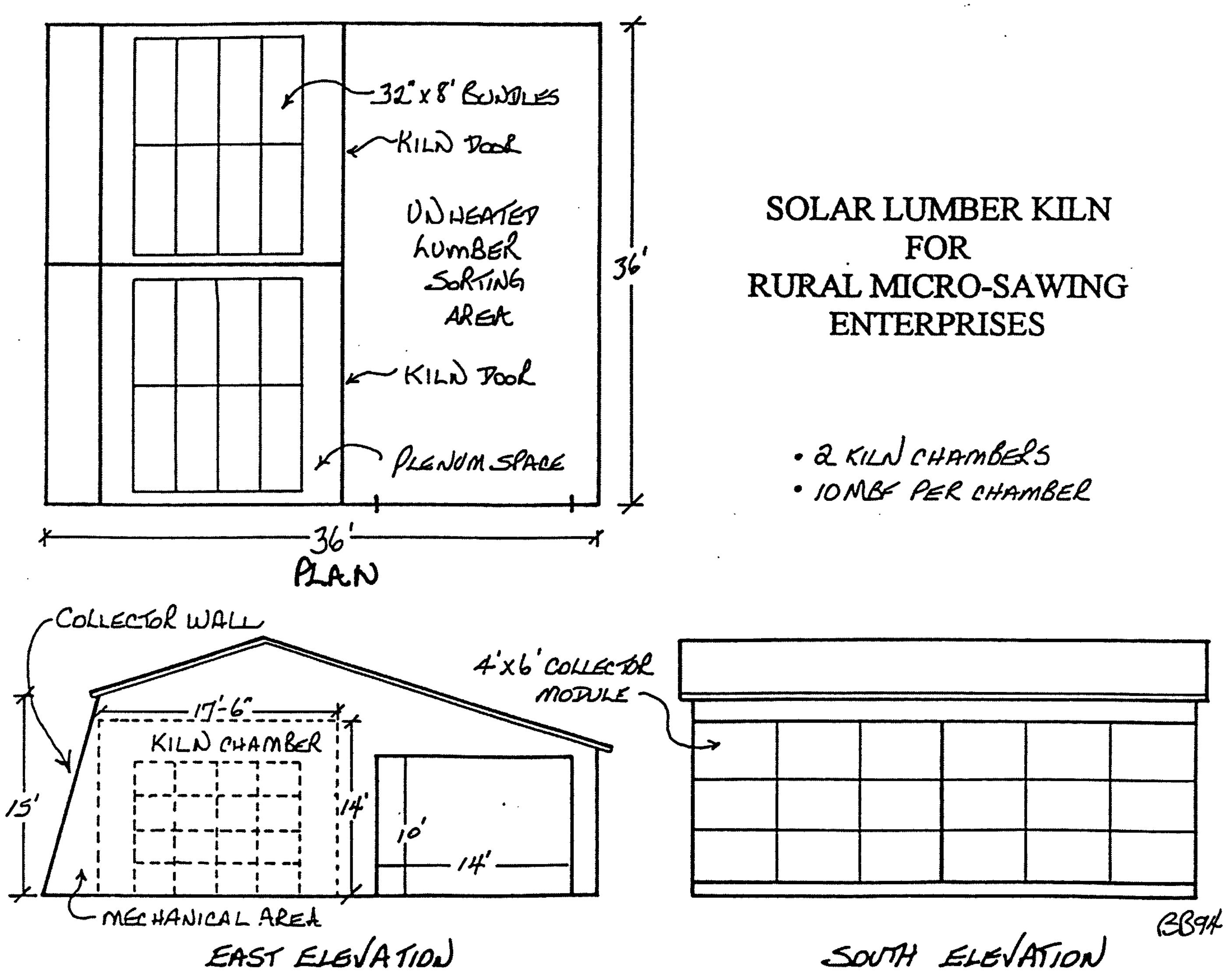


FIGURE 12: SUGGESTED DESIGN FOR SOLAR KILN

Once the configuration of the lumber pile is determined, the *plenum space* must be calculated and added to each side of the pile. The plenum space is the area needed by the fan-forced air to build up pressure before entering the stickered lumber pile. The width of the plenum is typically equal to the sum of the sticker spaces. In the example given, 59 sticker spaces at 3/4 inch require a plenum of about 3 foot, 6 inches. Thus, the total chamber width is 4 bundles at 32 inches plus 4 inches between stacks plus 3 foot-6 inches on both sides equals 18 foot-8 inches. Kiln chamber length is nominally 16 feet, but rough lumber would typically be about 4 inches over-length, so two 8 foot bundles end-to-end would occupy 16 foot-8 inches plus a small gap for forklift stacking. A minimum length would probably be 18 feet, allowing for some room for loading movement.

A kiln chamber length of 18 feet fits together well with the 4 X 6 foot modular collector units used in the Saskatchewan kiln. Three modules across the face and three modules up the face give a wall size of 18 X 12 - close to the size of the chamber itself. In terms of a collector to lumber ratio, this kiln has 21.6 square feet of collector per thousand board feet of lumber.

Shown on the north side of the kiln is an area labelled 'unheated lumber sorting'. This concept was not in the literature nor on the Saskatchewan kiln, but is suggested as a useful feature for consideration. One weak point in a solar kiln is the orientation of the loading doors on the north side - the least desirable location for an opening so large. The loading doors are probably the thermal weak link in any kiln, but a northern orientation would be especially undesirable in the case of a solar kiln. The lumber sorting area is an attempt to overcome this problem to some extent by providing a second wall to the north. Given that the kiln chambers are closed for several weeks at a time, why not use this space to hold lumber for sorting or processing? In the summer, it can be a weather-proof area for assembling kiln loads where the sun won't damage sensitive species like oak. Some operators will eliminate this area because it limits the room for loading with a forklift, especially with long lumber packs. Others might find it useful. With or without a sorting area on the north side, the seal obtained on the kiln doors is critical if heat retention in cool months is to be achieved.

Figure 13 outlines circulation, exterior venting, and supplemental heat details. Note that the ducting arrangement allows for adjustment to give full recirculation or full ventilation to the exterior and fresh air into the collector or a combination of recirculated and fresh air.

The circulation fans run at all times and are responsible for forcing the air through the pile. A flexible seal sits atop the lumber pile to prevent short-circuiting of the air flow. When the collectors generate heat, their fans cut in and the ducts to the collectors open to let warm dry air into the chamber.

Supplemental heat is added to the kiln via in-slab radiant heating pipes under the lumber pile. The insulation between the chamber slab and the rock storage is not shown. Any fuel could be used to supply hot water to the radiant system.

The arrangement of the collector ducts is such that both banks of collectors can be directed into one chamber in the case that one chamber is empty or that extra heat is needed to start or finish a load.

Note in the detail drawing that a reflective surface is specified in the collectors' foreground. Certain fine gravel surfaces can perform an important reflective function that increases radiation reaching the collectors by up to 85%, and can boost collector output by 40%. Experience with the Saskatchewan kiln has shown collector output to jump dramatically when a light snowfall covers the ground and provides this reflective function.

No attempt has been made here to detail the construction method for the kiln building because the possibilities are many. Each operator will select the best building system for his area. It is important, though, that the floor, walls and roof system be well insulated. A thick wall structure allowing up to 12 inches of cellulose insulation together with carefully installed air and vapour barriers is recommended.

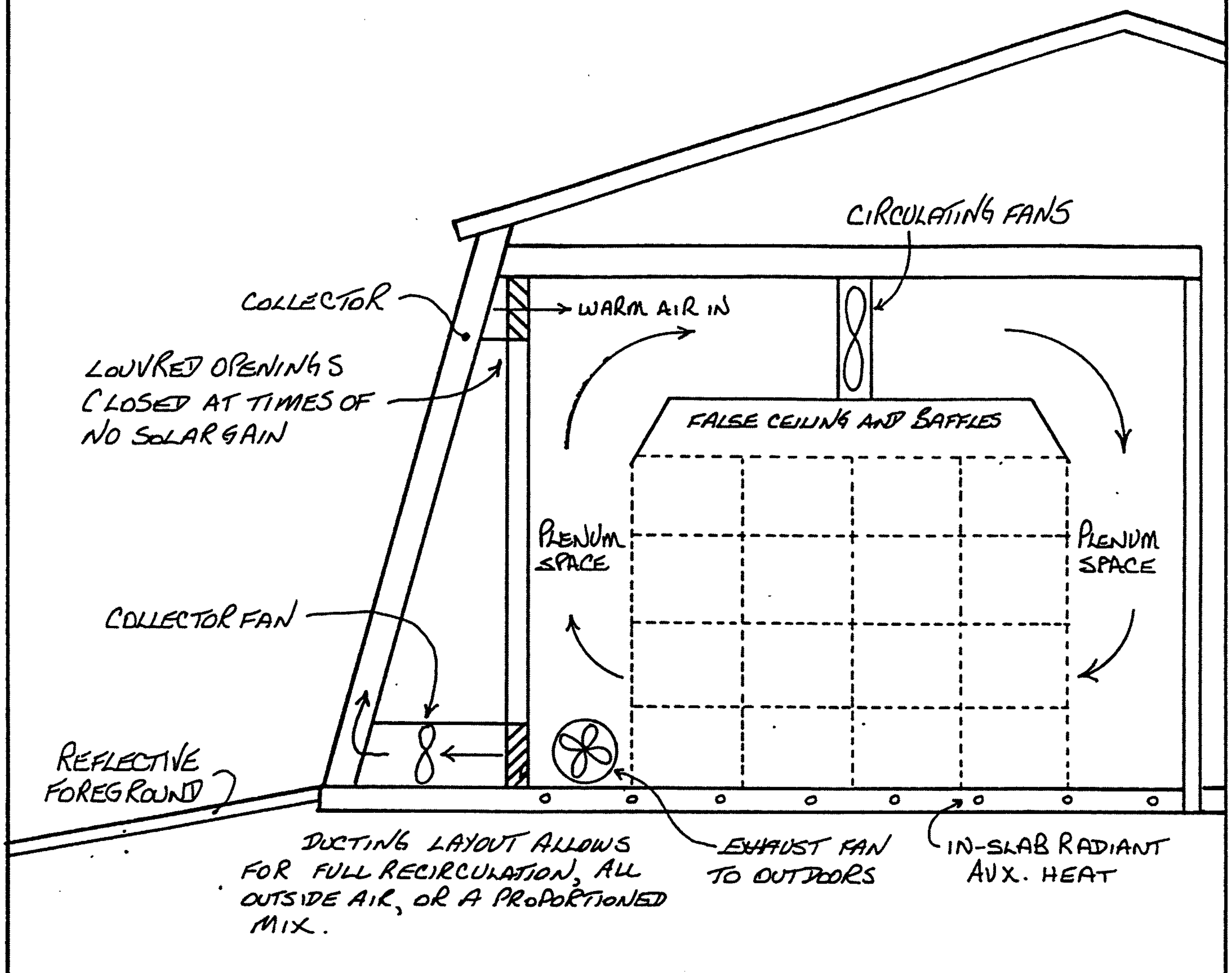


FIGURE 13: AIR CIRCULATION DETAILS FOR SOLAR KILN

Figure 15 is a photograph of the Saskatchewan kiln built in 1987. Humidity reduction was accomplished by exhausting air to the outside. Figure 16 shows a solar collector kiln constructed in Alberta which includes a rock bed under the kiln chamber. As shown in figure 14, moist kiln air is vented into the cool rock bed in order to drop its moisture. The condensed moisture will be run off from a low spot in the rock bed. Although rock beds have been shown in other solar kiln designs, they were typically designed to store heat. Operating data available after this kiln goes into production will demonstrate the effectiveness of rock bed dehumidification. At that point, an evaluation can be made against the additional cost of installing the rock bed.

Options for dehumidification are limited. Exhausting to the outside is quite acceptable in times of warm weather, but can lower chamber temperatures during periods of cool weather. One option may be to add a small dehumidification heat pump unit for use when exhausting to the exterior is not desirable. The attractiveness of the rock bed, of course, is that it is an option that has minimal maintenance requirements and does not increase the electrical demands of the kiln.

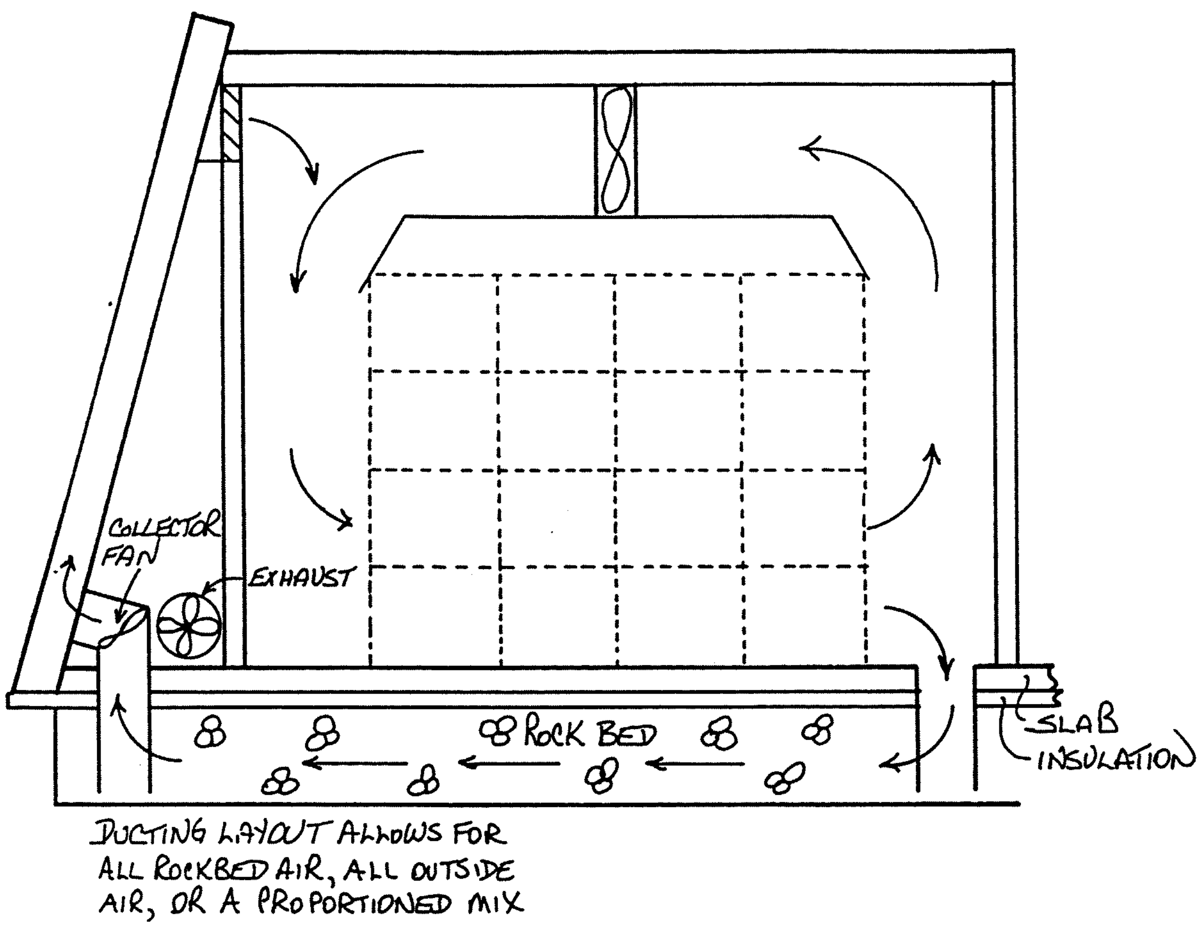


FIGURE 14: OPTIONAL ROCK-BED DEHUMIDIFICATION FEATURE

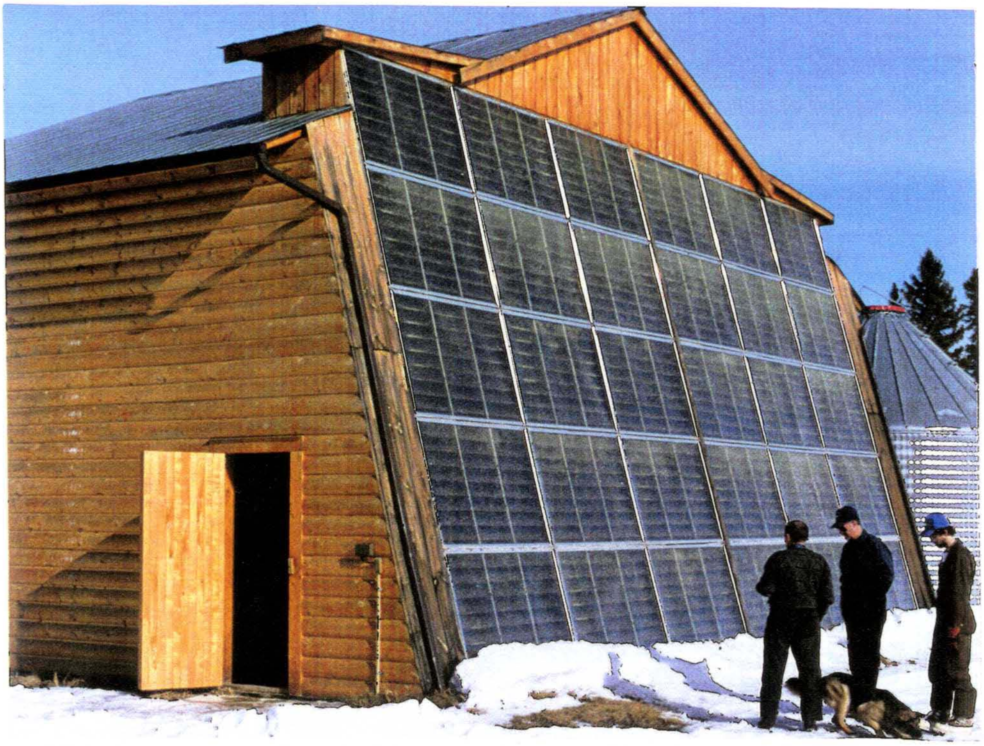
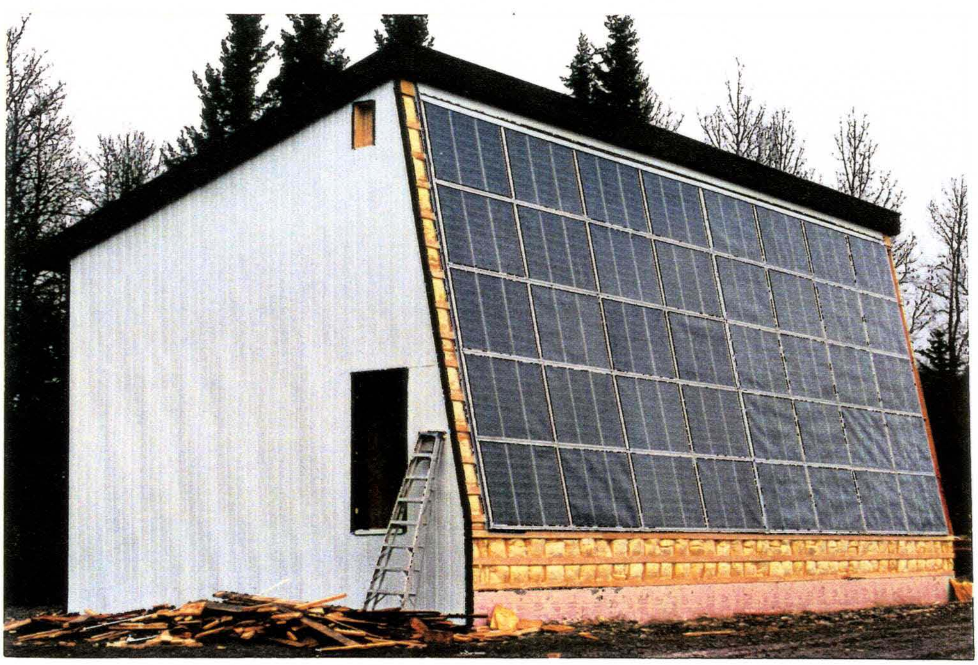


FIGURE 15: COLLECTOR TYPE SOLAR KILN NEAR PRINCE ALBERT, SASKATCHEWAN
40 Mbf CAPACITY, BUILT 1987 (HALLAND, ELLIS AND BELL)

FIGURE 16: COLLECTOR TYPE SOLAR KILN NEAR ROCKY MOUNTAIN HOUSE, ALBERTA
50 Mbf CAPACITY, OPERATIONAL EARLY 1994



APPENDIX A: DRYING CHARACTERISTICS OF NATIVE WOODS

		AV. GREEN M/C (%)		WEIGHT (LBS)		DRYING TIMES		
SPECIES[1]	DENSITY[2]	HEART-WOOD	SAPWOOD	1Mbf@ 80% M/C	1Mbf@ 6% M/C	AV. DAYS AIR DRY[3]	AV. DAYS CONV. KILN[4]	TYPICAL DRYING DEFECTS
Balsam Fir	.37	88	173	3096	1998	---	3-5	uneven moisture content
Lodgepole Pine	.40	41	120	3566	2299	15-150	3-5	warp
White Spruce	.35	(55)		----	----	30-120	4-6	water pockets, collapse, ring failure
East. White Cedar	.30	--	---	2905	1838	---	8-10	---
Basswood	.32	81	133	3004	2019	40-150	6-10	brownish chemical stain
East. White Pine	.36	50	175	3188	2007	60-200	4-6	blue stain, ring failure
Red Pine	.39	32	134	3842	2484	40-200	6-8	---
Black Spruce	.41	52	113	3565	2303	---	4-6	---
Jack Pine	.42	--	---	----	----	---	---	---
Tamarack	.48	49	---	4593	3030	60-120	3-5	shake
White Birch	.48	89	72	4510	3049	40-200	3-5	brownish chemical stains
Trembling Aspen	.35	95	113	3283	2125	50-150	6-10	water pockets, honeycomb, collapse
East. Cottonwood	.37	162	146	2907	1897	50-150	8-12	water pockets, honeycomb, collapse
Black Ash	.45	95	---	4218	2824	60-200	10-14	ring failure
Green Ash	.53	--	58	4970	3246	60-200	---	---
American Elm	.46	95	92	4311	2871	50-150	10-15	ring failure. warp
Willow	.36	(139)		3373	2232	30-150	12-16	honeycomb, collapse, water pockets
Bur Oak	.57	64	78	5438	3558	80-250	20-30	end checks, surface checks, iron stains, ring failure, collapse, honeycomb

Notes:
1. Species - rank ordered from least to most difficult to dry
2. Density - oven dry, green volume
3. Air Dry Time - 1" boards from green to 20% M/C, shorter time is for spring/summer, longer time for fall/winter
4. Conventional Kiln Time - 1" boards from green to 6% M/C

Sources: Dry Kiln Operator's Manual, USDA, Air Drying of Lumber, USDA, Canadian Woods, Prop. and Uses, UofT/Gov't of Canada

APPENDIX A: DRYING CHARACTERISTICS OF NATIVE WOODS (CON'T)

TENDENCY TO WARP

LOW	INTERMEDIATE	HIGH
SOFTWOODS		
White Pine	Tamarack	
Spruce	Jack Pine	
	Lodgepole Pine	
	Red Pine	
	Balsam Fir	
HARDWOODS		
Aspen	Ash	Elm
Birch	Basswood	Cottonwood
	Oak	
	Willow	

TENDENCY TO CHECK

LOW	INTERMEDIATE	HIGH
SOFTWOODS		
Cedar	Balsam Fir	Tamarack
Spruce	Jack Pine	
	Red Pine	
	Lodgepole Pine	
	White Pine	
HARDWOODS		
Aspen	Ash	Oak
Basswood	Willow	
White Birch		
Cottonwood		
Elm		
Maple		

Source: Air Drying of Lumber, USDA

APPENDIX B: BUSINESS PLAN

As noted earlier, the purpose of this business plan is to lay out the broad parameters for a rural micro-sawing enterprise in this region of Canada. In order to estimate kiln size, for example, the annual production from such an operation must be known.

In practise, very few businesses spring into being full-blown; most evolve over the course of a few years into the most appropriate form to suit local resources and markets. Still, it is worthwhile to outline a general form for the business to ensure that it includes the desired elements and makes financial sense.

What are the basic assumptions being made for this business? Perhaps the most important is the scale - the scale intended here is not unlike most agriculture in Western Canada - family or 'owner/operator' basis. A salary is included for the owner who would perform the bulk of the labour in the woods, sawmill and kiln operation and sales. Allowance is made for part-time or seasonal help, especially for logging and sawing operations. The year is divided into different duties in accordance with the seasons, logging while the snow is on the ground, sawing in warmer weather, etc. Some detail of various operations is included in order to ensure that realistic production is projected in keeping with the equipment used, the labour, and careful methods. It is assumed that the log source is private land and that the best selective and sustainable forestry methods are employed.

The Sawyer's Year

woodlot harvesting	-15 weeks	Oct.-Mar.
sawing	-25 weeks	Mar.-Oct
workshop	-10 weeks	Jan./Feb. Jul./Aug./Sept.
kiln operation	-continuous Feb.-Oct. with occasional monitoring	
Total	50 weeks	

Logging (15 weeks per year, owner and helper)

-'average log' defined as 8 feet by 12 inch top diameter
-approx. 60 board foot content per log (with bandmill)
-approx 1800 logs required per year to yield 100,000 board feet
-logging production: 120 logs/week or 24 logs per day (2 men+tractor/winch)
-costs for 100Mbf:

-purchase from landowner, on the stump, 15c/bd ft =	$15,000
-15 weeks owner's labour @ $700/wk =	10,500
-15 weeks helper's labour @ $400/wk =	6,000
-fuel, supplies, equipment maintenance	2,000
total log cost	$33,500

-OR, could pay landowners $335/Mbf for logs roadside

Sawmill Production (25 weeks per year, owner and helper)

- -hardwoods, cut for grade (slower sawing method, better product)
- -operator and helper, 1000 board feet per day
- -four days per week sawing, one day lost to sharpening, rain, etc.
- -25 weeks @ 4 days X 1000 board feet = 100,000 board feet/yr
- -cost of sawing 100Mbf:
  - -25 weeks owner's labour @ $700/wk = $17,500
  - -25 weeks helper's labour @ $400/wk = 10,000
  - -supplies, fuel, blades @ $110/Mbf = 11,000
  - -transport of lumber to kiln @ $20/Mbf= 2,000
  - total cost of sawing $40,500

Kiln Production

- -275 day season
- -5 loads/yr, average of 55 days per charge
- -5 loads X 20,000 board feet = 100,000 board feet
- -labour cost for kiln loading/monitoring - included as shop time
- -energy cost for kiln operation 100Mbf X $5.04/Mbf = $504

Workshop (10 weeks per year, owner working alone)

- -activities include kiln operation, value added processing, lumber sales, equipment maintenance
- -labour cost - owner - 10 weeks @ $700/wk =$7000

Equipment Investment

-farm tractor (used) and skidding winch	$10,000
-truck (used) and 5th wheel trailer	10,000
-sawmill	30,000
-kiln	50,000
-misc. tools	5,000
total equipment cost	$105,000

-capital amortized over 7 years @ $20,000/yr

Annual Expense Summary

-purchase of standing log supply from landowners	$15,000
-owner's labour - 50 weeks @ $700/ wk	35,000
-helper's labour - 40 weeks @ $400/wk	16,000
-expenses related to logging	2,000
-expenses related to sawing	11,000
-transport of lumber to kiln	2,000
-amortization of capital	20,000
-advertising, marketing, office support, etc.	4,250
total annual expenses	$105,250

Lumber Sales

- -initially only dried lumber for sale; value-added work during workshop time would improve sales income

-anticipated grade breakdown (simplified grading system)

15% high grade	-woodworkers	$2.00/bf =	$30,000
30% medium grade	-woodworkers	1.50/bf =	45,000
30% low grade	-agricultural, etc.	0.80/bf =	24,000
25% cull grade	-pallets	0.25/bf =	6,250
		Total	$105,250

The example given is for a mixed hardwood operation in southern Manitoba. A viable business plan would need to address the resource and markets for a given geographic area. Total lumber volumes would increase for a softwood operation, but sawing time and kiln time would be less per thousand board feet of lumber produced.

As to grade breakdown, the typical grade contents for our hardwood logs in southern Manitoba is not generally known for two reasons: previous processors have not shared their knowledge of our resource, and not enough hardwood production has been done with the bandsaw mills to show what quality of lumber they are capable of producing. Most of the previous sawmilling operations focussed on volume rather than quality.

Sales are directed at small industries, furniture makers, hobbyists, woodworkers and other local markets. At the time of writing, construction softwood material is selling for $675/Mbf, small cabinets shops are paying $2200/Mbf for hardwood, hobbyists and woodworkers are paying $2000 to 6000/ Mbf for hardwood at the retail level. Pallet makers are offering $250/Mbf for low grade material.

Few operators would borrow the full amount needed for equipment and purchase it all at the outset of starting a business. It is more likely to start with the sawmill and build up to a complete operation. Many variations are possible: work with a partner rather than an employee, begin by sawing and rent kiln space, begin the business part-time and build up to full time, etc.

The potential of value-added processing is not shown under lumber sales, although workshop time is allowed for it.

As alluded to in the introduction to this paper, an evaluation of forestry practises might consider *employment per log* as a basis. The above scenario generates $100,000 of activity using 1800 logs or 100,000 board feet of raw material.

APPENDIX C: RESEARCH PAPER ON THE SASKATCHEWAN SOLAR KILN - ELLIS AND BELL, 1989

A SOLAR POWERED DRY KILN FOR HARDWOOD LUMBER

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ABSTRACT

The performance of a solar-powered dry kiln, located at 53°N latitude in north-central Saskatchewan, was studied over a two year period to determine its suitability for drying both hardwood and softwood lumber to market specifications. Following modifications to the original design, the demonstration showed that hardwood lumber could be dried in both fall and early winter, as well as in spring and summer. An economic assessment indicated that the drying times needed to make the operation economically viable could be achieved. The resulting product has gained acceptance in the market place.

1. INTRODUCTION

This paper describes a project to test the feasibility of developing a low-cost dry kiln that would be suitable for drying hardwood lumber. Norplan Consulting, through its work with the Saskatchewan Council of Independent Forest Industries, had become aware that many of the province's small-volume wood processors would be able to benefit from such a kiln since it would permit them to process their lumber further and subsequently, market a higher valued product. The focus on hardwoods resulted from the fact that when the project was designed, little use was being made of that resource in north-central Saskatchewan. At the same time, consumers of hardwoods were having to rely upon products imported from eastern Canada and the United States.

In considering the type of kiln that would be most likely to meet the needs of small-volume wood processors, the project designers felt that, if practical, using solar collectors as the thermal source would be the preferred option. First, such a kiln would be more acceptable environmentally than a hog-fuel kiln. Second, although possibly requiring a greater initial capital expenditure, it should be cheaper to operate than any combustion or electrically-based kiln. Finally, with the proper air flow controls, it should not require a great deal of attention from the owner/operator when in operation. This latter point is quite important as far as the targeted market is concerned since many small-volume wood processors combine their logging and sawing operations with farming or other seasonal occupations. Thus, they may not be available to provide the daily attention other kiln types might require.

The question was whether a solar kiln was practical at such latitudes. The proposed kiln site is one of the most northerly farms in the province. At approximate latitude 53° 40", it actually borders on

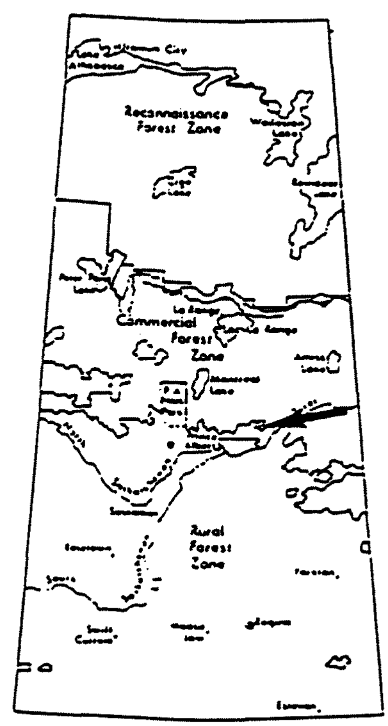

Fig. 1 Kiln site in north-central Saskatchewan.

the northern Provincial Forest. Feasibility investigations, while positive, also uncovered an unexpected benefit associated with a solar approach. Some experience has suggested that the diurnal variations in temperature and humidity that are an unavoidable part of a solar kiln with no heat storage capability may, in fact, alleviate some of the internal stresses that develop within the wood as it dries (Wengert and Oliveira, 1986). Hence common problems in kiln drying such as end checking and case hardening might not be as prevalent in a solar kiln.

To test the concept a project was designed to meet the following objectives:

1. To construct a solar powered dry kiln and to test its operation in all seasons.

2. To monitor the operating parameters of the kiln and determine appropriate operating schedules.

3. To monitor the variables that may effect length of drying time, costs and quality of product.

4. To determine, through a cost/benefit analysis, the feasibility of using solar energy as the sole thermal source for a dry kiln.

5. To make available information concerning the kiln's performance to other wood processors who might be interested in the concept.

1.1 KILN DESIGN

Figure 2 illustrates the design of the Halland kiln. The two-bay kiln, measuring

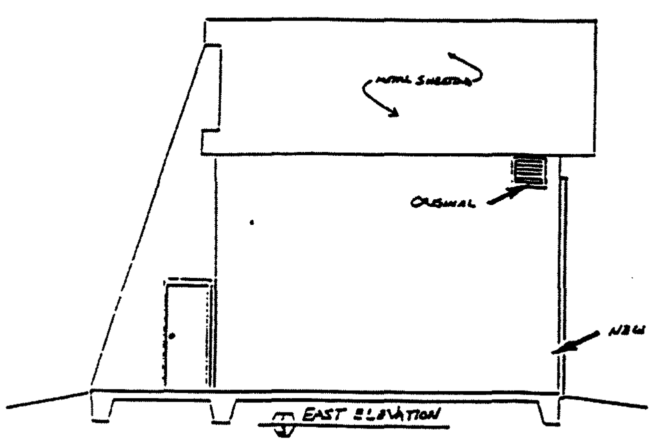

Figure 2. East elevation of Halland kiln showing the original and new location of exhaust vents.

22' x 40', is constructed from stacked 5x5's and topped with a conventional framed and insulated roof. Each kiln bay is lined with 6 mil vapor barrier which, in turn, is covered with pine panelling. Each bay can hold 20 Mbf Two loading doors each measuring 18.5' x 14.5' occupy most of the north wall of the structure. Attached to the south face of the kiln, the solar collector consists of 30 panels, each of which has an area of 22 sq. ft. The sloping design of the collector unit provides space for mechanical equipment and ductwork as well as for the monitoring equipment.

It should be noted that the ductwork design allows the output of the collector to be directed to either or both kiln bays. Since the project specifications called for only the right bay to be monitored, all test runs were conducted in that bay using the full output of the solar collectors.

1.2 MONITORING EQUIPMENT

All data were collected and stored using a Handar Model 570A Data Acquisition System equipped with the 570-7006 option which permitted remote data retrieval. The system was battery operated so that data acquisition and retrieval was possible even during power outages. The battery was maintained by a 12 v trickle charger.

Variables monitored included incident solar radiation, wind speed at the collector face, external temperature and relative humidity, temperatures of supply and return air, internal relative humidity, and hours of collector fan operation.

In all cases, data were collected each minute. Every hour the data were averaged for that period and stored to disk.

2. RESULTS Of MONITORING PROGRAM

Table 1 summarizes the results from all test runs of the monitored bay of the dry kiln during the project period, showing start dates, durations, and moisture contents at the beginning and end of each run.

It should be noted that the 1987 runs were considered to be "shakedown runs" to iron out mechanical and operational problems, and in fact significant problems with the kiln's operation were encountered in the April/May, 1988 run. During the run, the operators noted that the moisture content of the wood was not dropping as rapidly as they had expected. When the loading doors were opened so that the batch could be more closely examined, they discovered that the wood had mildewed and that there was moisture at the front of the kiln, close to the loading doors. It was also noted that the damper settings were forcing a high degree of air re-circulation.

Table 1. Summary of results of test runs of the solar-powered dry kiln.

Date	Wood Type	Duration (days)	Moisture Start	Moisture End
87/05/27	birch	66	36%	10%
87/11/14	pine	54	18%	9%
88/04/23	aspen	run aborted	34%	
88/09/01	birch	28	25%	6%
88/11/07	birch/ aspen	51	29%	14%

It was concluded that the problem was related to two factors. First, the batch was composed of freshly sawn, and hence very moist green aspen. Second, air flow patterns within the kiln permitted the collection of pockets of moisture-laden cool air, especially at the lower front of the kiln. Thermal stratification, particularly at night, magnified the problem. Because the humidity sensors were placed slightly above eye level at the back of the kiln, the situation was not detected by the monitoring equipment.

To remedy the situation it was agreed that the exhaust fans would be moved from their original location (see Fig. 2) to the lower front of the kiln. A simple duct system would be used to ensure that air was drawn evenly from across the front of the kiln. The volume of air re-cycled through the collector would also be restricted.

The above adjustments were made prior to the September, 1988 test run and the mildew/excess moisture problem has not reoccurred.

Figure 3 presents temperature data from the most recent test runs. The graphs illustrate that even during winter's shortest days there is a significant difference in temperature inside and outside the kiln. As well, in both seasons, the variations in daily average temperatures inside the kiln appear to be moderated, presumably as a result of the thermal mass of the drying lumber.

Figure 4 shows humidity data for the same periods. It is interesting to note that the relative humidity during the September run was, except at the outset, lower inside the kiln than that outside, while the reverse was true during the November/December run. It should also be noted that the September run was the most successful in terms of drying times during the entire project. Hence the lower

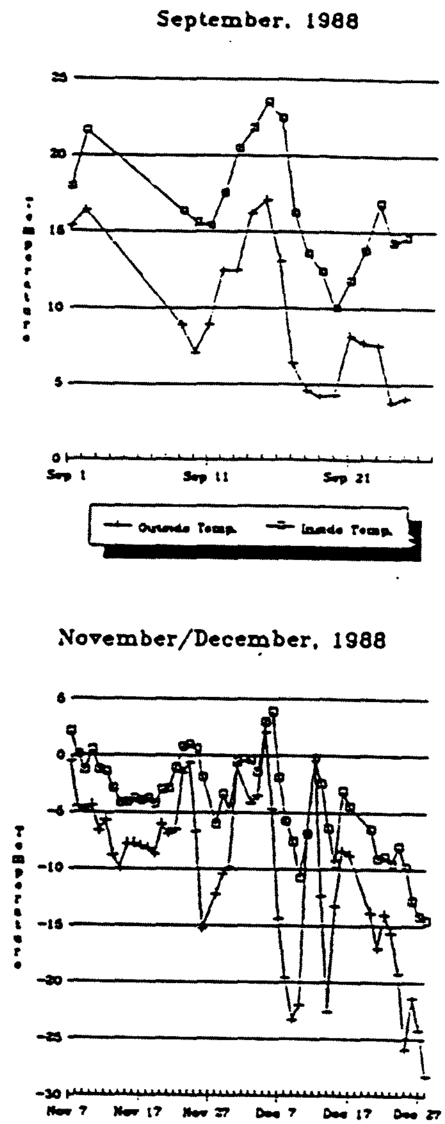

Fig 3. Inside and outside temperatures during two runs of the dry kiln.

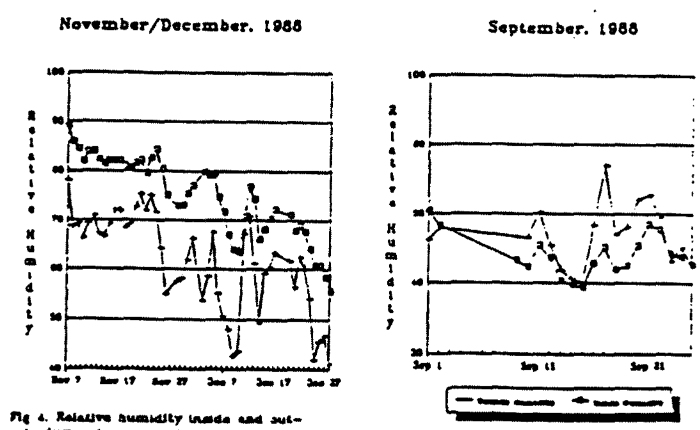

Fig 4. Relative humidity inside and outside during two runs of the dry kiln.

relative humidity inside the kiln may merely reflect the greater inside/outside temperature differential.

Figure 5 portrays estimated energy output from the solar collectors for the two periods, based upon pyranometer readings. Since these are area charts based upon daily average readings, they illustrate quite well the differences in collector output during the two periods, with the greater output coming in September.

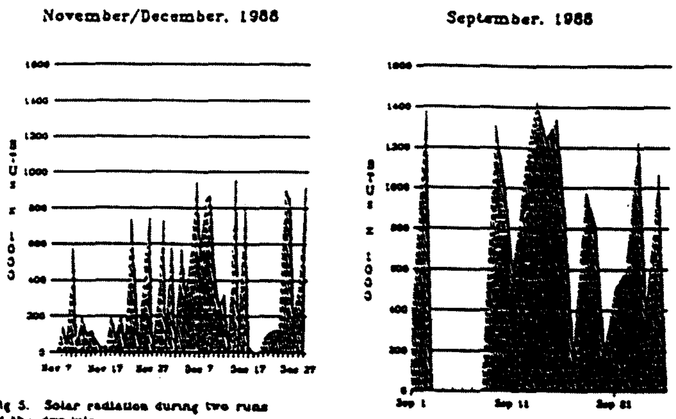

Fig 5. Solar radiation during two runs of the dry kiln.

To determine whether the calculated collector outputs were in fact representative of actual outputs, the two were compared for a three-day period, November 29 to December 1, 1988. Energy output measurements were based upon air flow volumes from the collector combined with collector supply and return air temperature differences. The results are shown in Figure 6.

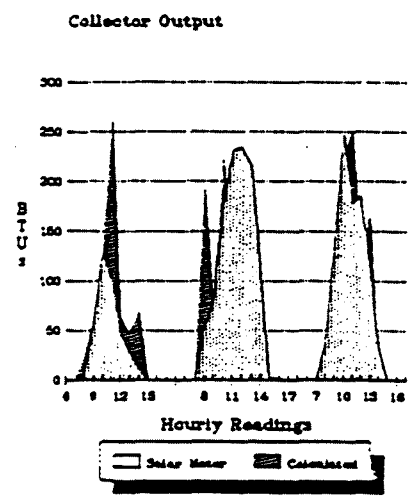

Fig 6. Calculated collector output vs. actual output, Nov. 29 to Dec. 1.

Finally, Figure 7 shows the diurnal variations in temperature and humidity that occurred inside and outside the kiln on September 15, 1988. As expected, both inside temperature and humidity fluctuations are somewhat damped, compared to those on the outside. However the daily cycle is still present and may help to explain why drying defects such as case hardening are less common in solar kilns

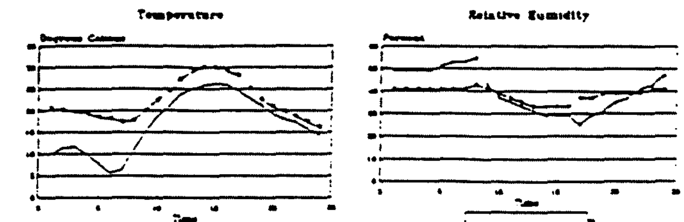

Fig 7. Temperatures and humidities outside and inside the kiln, Sept 15/88.

3. ECONOMIC ANALYSIS

It is difficult to compare the economics of a solar kiln, particularly one that is entirely dependent on solar energy for its thermal input, to the economics of more conventional approaches to kiln drying. When a conventional kiln is being used, the operator has complete control over the amount of thermal energy being applied to the lumber it contains. This control makes it possible to dry the lumber according to an approved schedule. In turn, the ability to schedule in a reasonably precise fashion makes it possible to project kiln throughputs on an annual basis. These volumes can then be used in a cost-benefit analysis so that the use of hog fuel as an energy source can be compared, for example, with the use of electricity.

Applying such an approach to analyzing a solar kiln is less satisfactory since drying time, and consequently kiln throughput, are much less predictable. The preceding section pointed out that drying times, depending on the season and the weather, can range from 27 to over 60 days. Thus throughput in one year might vary quite significantly from throughput in another.

As a result of the above, we have used a different method to assess whether the solar approach used in this project is a viable one. We have calculated the average drying time that would have to be achieved, under a variety of scenarios, for the kiln to break even. We then compare that to actual kiln performance.

The following assumptions have been made for the purpose of these calculations:

- the kiln will be in actual operation for only 200 days per year. This recognizes the seasonal nature of the operations of many small-volume processors, and provides ample time for loading, unloading and maintenance. It probably represents an underestimate of actual usage.

- the capital cost of the kiln, $45,000 at 12% interest, will be retired in 15 years.

- no "return on investment" will be calculated for the kiln itself.

Table 2 summarizes annual projected input costs for a range of drying periods, when the kiln is drying birch lumber. Calculations are based upon the assumptions that the annual electrical costs and the annual capital cost of the kiln will not vary with the volume of lumber being processed by the kiln. On the other hand, the cost of the green lumber and the labour associated with loading, unloading and operating the kiln will obviously change as throughput increases.

Thus in an operating year of 200 days where the kiln has an average drying duration of 20 days and a capacity of 20 Mbf

Table 2. Projected annual input costs based upon selected drying times, using the noted variables. For birch lumber.

Average daily electricity cost	$3.02
Cost of green lumber/Mbf	$300.00
Kiln capital value	$45,000.00
Labour and machine cost/hr	$70.00
Days/year of operation	200

Duration (days)	Electricity per year	Green Lumber	Capital	Labour	Total Cost
20	$604.00	$60,000.00	$6,380.00	$5,600.00	$72,584.00
25	604.00	48,000.00	$6,380.00	4,480.00	59,464.00
30	604.00	40,000.00	$6,380.00	3,733.33	50,717.33
35	604.00	34,285.71	$6,380.00	3,200.00	44,469.71
40	604.00	30,000.00	$6,380.00	2,800.00	39,784.00
45	604.00	26,666.67	$6,380.00	2,488.89	36,139.56
50	604.00	24,000.00	$6,380.00	2,240.00	33,224.00
55	604.00	21,818.18	$6,380.00	2,036.36	30,838.55
60	604.00	20,000.00	$6,380.00	1,866.67	28,850.67
65	604.00	18,461.54	$6,380.00	1,723.08	27,168.62
70	604.00	17,142.86	$6,380.00	1,600.00	25,726.86
75	604.00	16,000.00	$6,380.00	1,493.33	24,477.33
80	604.00	15,000.00	$6,380.00	1,400.00	23,384.00
85	604.00	14,117.65	$6,380.00	1,317.65	22,419.29
90	604.00	13,333.33	$6,380.00	1,244.44	21,561.78
95	604.00	12,631.58	$6,380.00	1,178.95	20,794.53
100	604.00	12,000.00	$6,380.00	1,120.00	20,104.00

it will require 200 Mbf of birch lumber. At $300/Mbf, this represents a $60,000 raw material cost.

Experience has also shown that the loading and unloading of the kiln each require about 4 hours of man and machine time. However, unlike conventional kilns that require careful monitoring during their operation and hence additional labour costs, the solar kiln requires little or no additional labour input during operation. Hence under the above scenario annual labour and machine costs would be $5600 (10 charges x 8 hrs x $70). These figures are shown in the first row of Table 2.

Since the kiln was not metered separately, the annual electrical costs were estimated on the following basis. Virtually all electrical consumption is related to the operation of circulation fan motors These consisted of:

2 - 1.9 hp collector fan motors
2 - .25 hp ventilation fan motors
4 - .33 hp circulation fan motors

Under normal conditions the circulation and ventilation fans run continuously. However the collector fans only operate when the collectors are producing heat. Using data from February and July, it was calculated that the collector fan operated for an average of 6.26 hours a day. Thus, using a conversion factor of 1 hp = 0.745 kw and the electrical rate schedules for the area, the daily electrical costs for the kiln were determined to be $3.02 per day or $604 for the 200 day operating season.

Similar analysis were carried out for pine and aspen green lumber, and finally the input costs were compared to expected income, based on current market values for the three lumber types.

Figure 8 captures graphically the relationship between gross income and

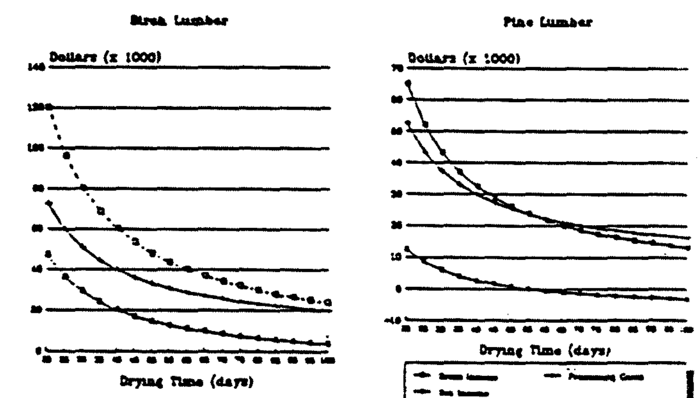

Fig 8. Gross income, net income and processing costs for birch and pine lumber.

processing costs for the two extremes, birch and pine. It points out that for birch lumber, provided the output quality is sufficiently high to command current market values, even two loads a season will cover all costs associated with the kiln's operation and return a modest profit. However, experience is also showing that birch requires significantly longer periods to dry to the desired moisture content than either poplar or pine. One could reasonably expect durations in the vicinity of 45 days on average. Even at that length, return on investment is impressive.

For the lower valued woods, the economics get a bit tighter, as illustrated by the graph representing the costs and income associated with drying pine. It can be seen that the kiln would just break even if the average duration was 55 days, and profits would be modest until one achieved a 30 day average duration. Fortunately, since both aspen and pine are fast drying woods, experience is suggesting that the 30 day target is achievable.

3.1 COST COMPARISONS

As noted at the outset of this section, making cost comparisons between solar kilns and those using more conventional approaches is difficult. However the following information will serve as a general guide.

First, most references to drying costs include only energy and labour costs, and not green lumber and capital costs, as we have done in Tables 6 and 7. Excluding those latter costs and making the calculations based only on energy and labour yields the following:

Average Duration	Cost/Mbf
30 days	$32.61
40 days	34.04
60 days	36.86

These figures compare quite favorably with accepted industry estimates (Laurie McGregor, Finn-Mac, pers. com.) for the various kinds of kilns.

Type	Cost/Mbf
Steam (wood waste)	$30 - 35
Steam (natural gas)	75 - 80
Dehumidification (elec.)	60 - 70

It can be seen that the processing costs associated with the solar approach are quite competitive.

4. CONCLUSIONS

1. This project has demonstrated that a solar powered dry kiln can dry both hardwoods (birch and aspen) and softwood (pine) in such a way as to meet the quality standards of the market place. Further, the results have supported the contention that the diurnal variations in temperature and humidity that occur within the kiln reduce some of the drying problems, particularly case hardening.

2. A small-volume solar powered dry kiln can be cost effective. The degree of profitability is determined by the price differential between green and kiln-dried lumber, and by the length of the drying process.

3. The solar approach to drying lumber is not as labour intensive as conventional kilns. Hence operating costs are lower.

4. The kiln will dry lumber in all seasons of the year. However drying time increases markedly in the period from November to February.

5. Because of the less predictable nature of drying times, the solar approach to kiln drying is best suited to small-volume processors who may not be faced with critical production schedules.

6. Smooth air flow with in the kiln, and the avoidance of dead air pockets is essential if drying defects are to be avoided.

ACKNOWLEDGEMENTS

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