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AN EVALUATION OF WOOD KILN CONTROL PRACTICES

Canada

Translation from French to English is compliment
of the Canadian Industry Program for Energy Conservation (CIPEC).

AN EVALUATION OF WOOD KILN CONTROL PRACTICES

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April 2003

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Summary

This report analyses softwood-drying practices in Canada and identifies the R&D efforts required in this field. These issues need to be examined in order to address environmental concerns and implement solutions that will improve energy efficiency and reduce greenhouse gas emissions.

Developing advanced softwood-drying control systems would reduce energy use and enhance product quality. According to some researchers, the potential reduction in energy use by dry kilns in Canada would be 5.5 PJ per year, or 335 kT per year in carbon dioxide (CO_2) emissions. Furthermore, it is estimated that CO_2 emissions could be reduced by an additional 90 kT per year through a decrease in the amount of lumber that is downgraded.

This study aims to give an overview of the main trends in developing control systems and to identify barriers to their introduction. It will also serve as a starting point for launching and directing projects on control procedures for lumber-drying in cooperation with the industry, universities, private and public laboratories, manufacturers and users.

In keeping with this objective, researchers for this study surveyed members of the Quebec Lumber Manufacturers' Association and a few mills in British Columbia. The main findings are as follows:

- Industry opinion is that its facilities are sufficiently modern to meet current market needs.
- Industry opinion is that quality (grade reduction / rejection rate) is the most significant factor when evaluating drying systems.
- Because it is not easy to measure the quality of the drying process, drying time is most often used to evaluate drying performance.
- Although quality was identified as the main variable in the drying process, the proportion of under-dried and over-dried lumber units was 9 and 16 percent, respectively.
- Operators play a significant role in drying operations (they manage the process before, during and after drying), and their actions affect the results of the process considerably.
- The decision to purchase a drying-control system is driven more by the acquisition of a kiln than by requirements related to the process itself.

The researchers reviewed current technical knowledge of the main dry kiln control systems by considering two types of control: air temperature control when drying; and setting up drying programs. The figures in this report illustrate the use of these two approaches along with various other control methods employed in the industry.

There are five softwood kiln controller manufacturers in Canada, which together account for 75 percent of the Canadian market. Although they use similar controllers, there are differences in how drying programs are set up and how changes in moisture content are measured during drying. In spite of recent technological advances, proper drying operations still depend on operator expertise.

R&D on new measurement instruments and mathematical models has not resulted in advanced kiln controllers so far. Innovation in this area has not kept pace with the advances in other leading sectors. One technical problem that has not been resolved is that of measuring moisture content. In spite of more than 20 years of effort, mathematical models are still being developed in the scientific community, and few applications resulting from this work have benefited the industry other than those supporting operator training.

The research community and the industry acknowledge that the development of an advanced controller represents a promising avenue for improving the lumber-drying process. Unfortunately, problems in modelling the drying process and measuring moisture content remain represent major obstacles to the development of high-efficiency controllers.

Another obstacle relates to the difficulty of evaluating the financial benefits that would accrue from potential advances with the necessary speed and accuracy. These, then, are the key factors hindering the introduction of new drying technologies. They also explain why length of drying time is still the most frequently used control variable, despite the fact that the industry considers finished product quality more important. Furthermore, it appears that operators’ actions significantly affect what happens not only in the kiln but at all stages in the process, from the sawmill to shipping.

In view of this, we believe that a system for monitoring the entire drying process is worth investigating. Such a system would

- serve to collect all data generated by measuring instruments at all stages in the process, from the sawmill to the planing mill
- help to establish productivity and quality indicators for measuring the monetary value of process enhancements introduced by operators
- make it possible to provide a rationale for other promising research approaches such as multivariate analysis and experimental design

This approach would make it possible to enhance control of the drying process and process quality while also revealing potential energy savings.

Acknowledgments

This report was produced with financial assistance from the Program for energy research and development program (PERD- POL 4.3.3 SENSCON). The authors wish to thank the following for their invaluable contributions and support:

Gilles Jeanrie, Quebec Lumber Manufacturers' Association

Radu Pantea, Natural Resources Canada

Kiln controller manufacturers

industry representatives who participated in the survey

François Robichaud, Luiz Oliveira, Dave McRae and Dany Normand, all of Forintek Canada Corp.

Members of the public can access this report in PDF format by visiting the CETC-Varennes Web site at cetc-varennes.nrcan.gc.ca.

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1 Introduction

This report analyses softwood-drying practices in Canada and identifies the R&D efforts needed in this field. These issues need to be examined in order to address environmental concerns, improve energy efficiency and reduce greenhouse gas emissions that contribute to climate change.

Lumber production is a major economic sector in Canada, with annual sales of about $8 billion in 2001. It is also a large energy consumer. Drying operations account for most of the industry's energy use, consuming almost 121 PJ per year, about half of which comes from fossil fuels.

Although the efficiency of the drying process continues to be examined, in recent years there have been no technological breakthroughs to make the process more efficient. Lumber drying continues to be based on empirical drying programs and operators' judgment. An initial examination of the situation suggests that a number of factors—e.g., the complexity of the phenomena involved, the lack of technical means to measure lumber moisture content accurately, the relatively low cost of energy, and a lack of emphasis on defining product quality—are making technological developments in this field a challenge.

One avenue to explore is the development of advanced control systems. These would reduce energy consumption and improve quality at the same time, and experts[a] agree that advanced control systems could reduce the energy use of some types of industrial kilns by 5 to 31 percent and generate payback periods of less than two years.

There is economic justification for introducing new control systems for dry kilns in Canada. For example, if such systems reduced energy use by an average of 18 percent and were installed in 50 percent of kilns that run on fossil fuel, energy use by dry kilns in Canada would decline by about 5.5 PJ per year, which is equivalent to reducing CO_2 emissions by 335 kT per year.

It is safe to assume that advanced control systems would cut down on product quality losses, which currently make up an estimated 10 percent of production. If advanced control systems were to reduce losses by 25 percent, the Canadian industry would save nearly $100 million a year. In addition, reducing the number of product rejects would reduce CO_2 emissions by an estimated 90 kT per year.

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[a] CADDET Report No. 12 (1994).

This study aims to give an overview of the main trends in developing control systems and to identify barriers to their introduction. It will also serve as a starting point for launching and directing projects on control procedures for lumber drying in cooperation with industry, universities, private and public laboratories, manufacturers and users.

Another purpose of the study is to stimulate reflection on the issues and encourage the development of technologies to enhance drying practices. Although detailed, this study covers only part of the topic. The authors encourage readers to provide them with any information that could help improve or update the study.

1.1 Description of the Softwood-Drying Market[b]

The softwood lumber industry in Canada produces an estimated 66 million m^3 of product annually[c]. British Columbia has the largest share of production, with 46 percent; followed by Quebec, 24 percent; Ontario, 12 percent; and Alberta, 9 percent. The remainder of production is from the other provinces and territories. In 2001, total sales for the sector were about $8 billion.

In 1999, British Columbia delivered 15 percent of its production to the Canadian market, 67 percent to the U.S. market, 13 percent to the Japanese market, and the balance to Europe. In 2001, Quebec produced about 43 percent for the Canadian market and 57 percent for the U.S. market, shipping very little overseas. Alberta produced 50 percent for the Canadian market and 42 percent for the U.S. Dry lumber production accounts for an estimated 90 percent of total lumber production. Exports must meet a number of phytosanitary standards, and as a result nearly all exports are dried. If they are not dried, they are pasteurized.

In 2001, the dry lumber sales premium was about $100/MFBM[d]. The industry uses more than one method to calculate drying cost, and estimates for softwood vary from $15/MFBM to $25/MFBM. In 1999, the cost of fuel and electricity consumption by the Quebec sawmill industry was about $100 million.

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[c] In comparison, hardwood production is 1.7 million m^3 annually.
[d] In 2001, the average sale price was $460.

1.2 Organization of this Study

To clearly identify trends and R&D requirements, this study

1. describes technical knowledge of the main dry kiln control systems
2. reviews the main commercial products on the market
3. reviews research and development in this field in Canada
4. reports on a survey of drying practices in the industry
5. reports on a survey of industry members on what is required to improve the drying process

The study also seeks to answer the following questions:

1. What are the main barriers to developing and introducing advanced control systems?[e]
2. What would be the target applications for such systems?

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[e] Advanced control systems use algorithms to calculate how to upgrade performance of the target system. The Softsensor reserved title is a new name for the addition of algorithms to measurement instruments to upgrade the performance of those instruments.

2 Present Knowledge of Kiln Control Structures

In order to describe the technologies available from controller manufacturers, mill-drying operations and R&D efforts, we felt it would be helpful to delineate an overall kiln controller structure as a means of describing the present state of knowledge. This structure will serve as a reference point for the study.

Drying lumber in a kiln with controlled air temperature and humidity conditions is the process most widely used in Canada[f] to reduce the moisture content of softwood. Kiln control systems[4] are designed to change the moisture content of the lumber load while keeping drying time to a minimum, limiting the effect of drying on grade reductions and minimizing energy use. Since no control system can act directly on moisture content, kiln operation is a function of air conditions. The operator determines the relationship between changes in moisture content and air conditions in setting the drying programs (schedule). To visualize the concept, we will refer to two types of control[5]: control of kiln air temperature and the setting up of drying programs.

2.1 Kiln Control Structure

Using a block diagram automatic control language, the structure shown in Figure 1 links all the components of the kiln control system structure. The main chain contains the PID (“proportional,” “integral” and “derivative”) regulator, the systems that are under control such as heating and humidification,[6] the air and the lumber stack.

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[f] See Appendix A: Kilns and their Environment.

[4] See Appendix B: Additional Information on Dry Process Control.

[5] See Appendix C: Dry Kiln Control Structure.

[6] Figure 1 does not show dehumidification and humidification systems, but they are parallel to the heating system.

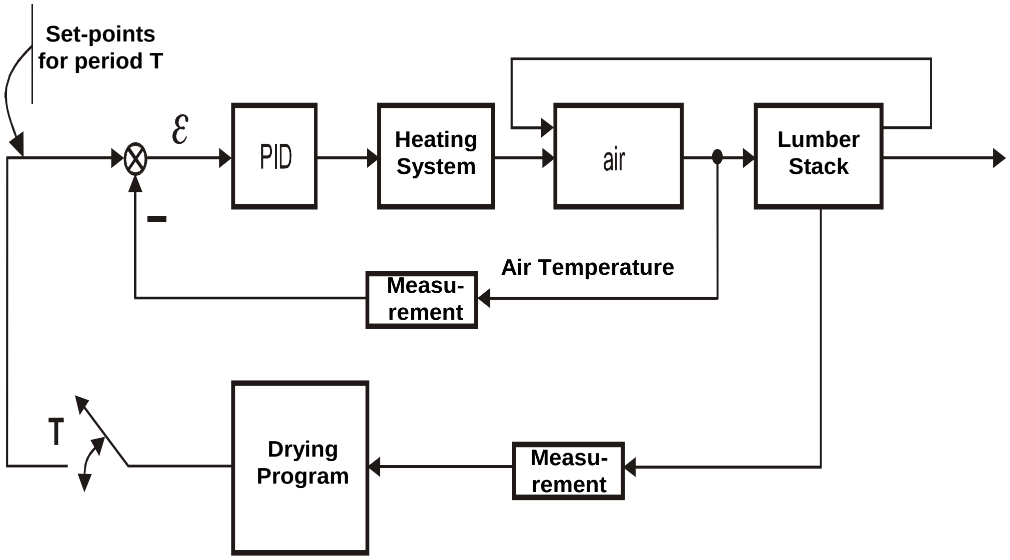

Figure 1. Block diagram of lumber-drying system

2.2 Air Temperature Control

Figure 2 shows part of the overall structure, specifically the components required to regulate the dry bulb and wet bulb temperatures to create the right air conditions for drying the lumber. The structure takes the form of a classic control loop that provides for automatic air temperature maintenance at the lumber stack entry point.

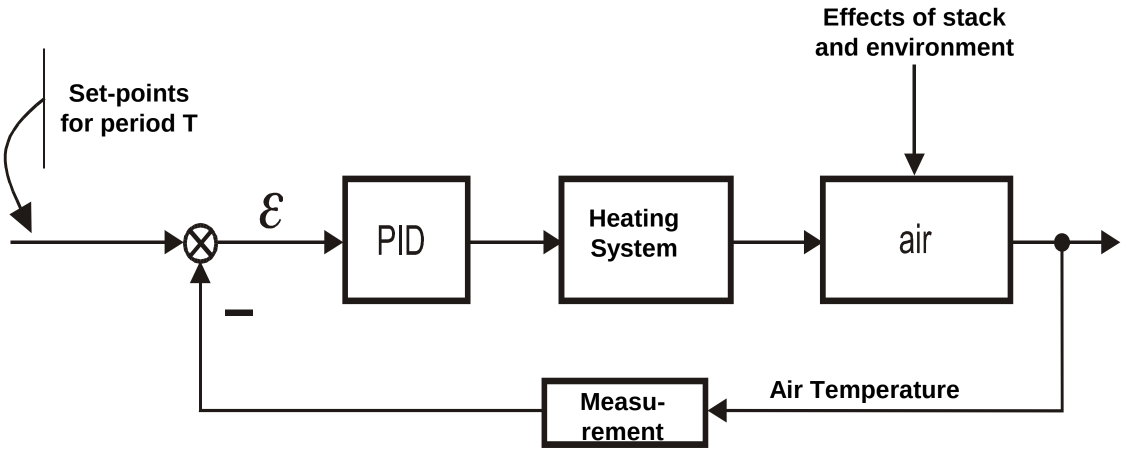

Figure 2. Details of block diagram of control loop

The components of the loop are the measurement instruments, the controlled systems (heating, humidification, ventilation), the PID regulator and a comparator for determining the difference between the actual temperature in the kiln and the target temperature set by the drying program (drying schedule).

With this loop, the system can adjust to environmental fluctuations and still achieve results that are accurate, fast, stable and reliable. All manufacturers offer this control loop, with a few variations.

2.3 Setting up Drying Programs

The second structure (see Figure 3) links air temperature with the lumber-drying process. We refer here to automatic tools for setting up drying programs. By measuring specific drying parameters such as the humidity of individual lumber units, the weight of the control units and temperature drop across the load (TDAL), the controller generates the temperature changes set by the drying program (drying schedule).

The main difference between this loop and the one shown in Figure 2 is that it operates in successive, pre-programmed stages (sequencer) instead of taking corrective action in response to observed error (regulation). Moreover, the sequences are established by the operators on the basis of their knowledge of the drying process, load properties, kiln operation and so on. This is essentially what differentiates the main kiln controllers from one another. Manufacturers offer a variety of tools to help operators set the drying programs.

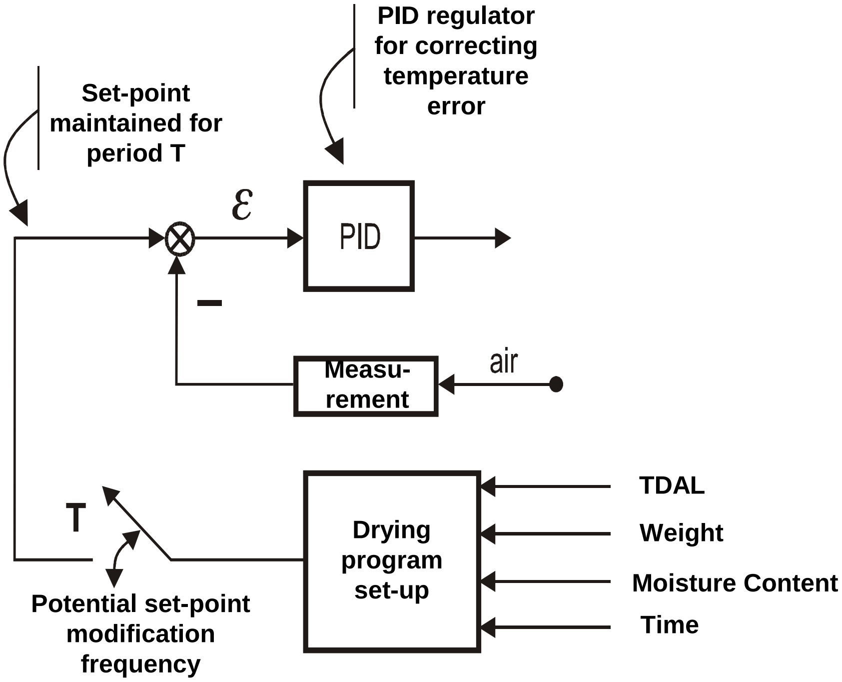

Figure 3. Details of block diagram with drying program

We will refer to the three figures above in presenting the control systems available from manufacturers in the softwood-drying industry.[7]

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[7] See Appendix E: Main Control Systems.

3 Review of Leading Kiln-Controller Manufacturers

In this section we describe the products available[8] in Canada from softwood kiln controller manufacturers. The results of our survey[9] indicate that five manufacturers account for 75 percent of the dry kiln controller market in Canada—three Canadian companies, one U.S. company and one European company—and all are well established in Canada.

In western Canada,[10] one of the manufacturers, Salton Fabrication Ltd., enjoys the largest share of the kiln controller market, with Coe Manufacturing Company and a few others holding the rest. In eastern Canada,[11] the market is controlled mainly by CATHILD Inc., Malahat Energy Corporation, Salton Fabrication[o] and Secovac.

In January 2003, we contacted the main softwood kiln controller manufacturers in Canada. Data in the following tables were obtained by telephone interviews. Referring to Figures 1, 2 and 3, we will describe

- the systems governed by the controllers
- the control loop
- drying program set-up procedures.

3.1 Controlled Systems

Table 1 lists the main controller-regulated systems according to manufacturer specifications. The first such system—the heating source—regulates air temperature while the vent and humidification systems maintain air humidity at the set-points.

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[8] There is a significant difference between current market shares and kiln stock. Our review focuses on market shares because it is the manufacturers who are currently active in the market who are most likely to bring about changes in drying practices. Furthermore, we assume in our study that the kilns and controllers are sold by the same manufacturer, even though this is not always the case. Frank Controls in western Canada and Secovac in eastern Canada are endeavouring to sell their controllers to customers that use all types of kilns.

[9] Sources: Survey presented in the next section and Forintek Canada Corp. internal survey of Prairie sawmills in 1999–2000. The accuracy of the figures cannot be guaranteed, so they are provided for reference only.

[10] British Columbia, Alberta and Saskatchewan.

[11] Most of the sawmills in eastern Canada are in Quebec, with a few in Ontario and New Brunswick.

[o] Since 2002, Salton has had no sales representatives in eastern Canada.

Table 1. Description of dry kiln control system designs by leading manufacturers

Manufacturers		**CATHILD Inc.**	**Coe Manufacturin**	**MEC Kilns Inc.**	**Salton Fabrication Ltd.**	**Secovac Inc.**
Sources of heat in kiln	Steam	x	x	x	x	x
	Overheated steam	x	x		x	
	Hot water	x	x	x	x	x
	Hot oil	x	x		x	x
	Direct fire	x	x	x	x	x
Types of ventilation	Single-pass	x	x	x	x	x
	Double-pass	x	x	x	x	x
	Set speed	x	x	x	x	x
	Variable speed	x	x	x	x	x
	Longitudinal shaft drive		x		x	x
	Perpendicular shaft drive		x		x	x
	Direct air coupling	x	x	x	x	x
	Adjustment of ventilator angles	x	x	x	x	x
Types of humidification	High-pressure steam jet	x	x	x	x	x
	Low-pressure steam jet	x	x	x	x	x
	Water spray jet	x	x	x	x	x
	High-pressure water spray jet	x	x		x	x
	Water-steam mix	x		x		x
Loading methods	Bundle loading	x	x	x	x	
	Rail loading	x	x	x	x	x
	Other					
Buildings	Aluminum walls	x	x	x	x	x
	Stainless steel walls			x	x	x
	Concrete walls		x		x	x
	Wall insulation	R-27	R-23	R-24	R-24	R-22
	Ceiling insulation	R-27	R-23	R-30	R-22	R-22

In western Canada, the leading sources of heat in descending order of use are gas (direct-fire), hot oil, hot water and steam. In eastern Canada, the main sources are steam and gas (direct-fire).

In most cases, choice of heating sources involves a trade-off between energy supply costs and facility costs. Since a kiln requires twice as much power at the start of the drying process, the infrastructure of certain types of facility can be very expensive, so installing them is not an attractive option.

The ease with which a system can be controlled should be a factor in choosing the heating source, but this does not seem to be the case. If it were the primary selection criterion, all manufacturers would agree that an indirect serpentine-coil heating system (steam, hot oil, hot water) would be the best choice because it provides for the most effective distribution of heat and best local area control.[12]

The type of ventilation also varies from one facility to another. Double-pass and double-rail systems are the most common. Longitudinal, perpendicular and direct shaft ventilator drives are all used to the same degree. Variable-speed ventilation is gaining popularity in new facilities. Fresh air intake through building vents is comparable from one manufacturer to another. Here, too, the choice of technology is determined more by installation costs than by how user-friendly the system is.

Note also that the choice of type of humidification is tied closely to the choice of heating source. If steam is available, steam injectors are installed or water sprayers are preferred. This customized technology is becoming increasingly widespread.

Based on Table 1, we can conclude that manufacturers' products are similar to one another and that customer orders are in many cases based more on installation cost than on operating cost.

3.2 Air Temperature Control

Table 1 summarizes the various air temperature control devices available from manufacturers.

"Computer support" refers to the type of computer used to determine and maintain set-points for air conditions in the kiln. Personal computers (PCs) and programmable logic control (PLC) computers provide for the same type of control. At one time, PLCs were more reliable than PCs.

All the manufacturers listed in Table 2 manage set-points using PC computers, and usually a single computer manages all the kilns. There are variations: in some systems, PLCs regulate air conditions; in others, PCs

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[12] Choosing between hot oil and steam in particular usually depends on the legislation in the region concerned. This is why there are many steam systems in eastern Canada and a prevalence of hot oil systems in western Canada.

perform this function. Several PLCs can be used at the same time, so the control function can be applied across subgroups of kilns. Again, the choice of technology involves a trade-off between system reliability and installation cost.

Table 2. Description of manufacturers' proposed means of regulating air conditions

Manufacturers			**CATHILD Inc.**	**Coe Manufacturing**	**MEC Technology Inc.**	**Salton Fabrication Ltd.**	**Secovac Inc.**
Computer support		PC	x	x	x	x	x
		PLC		x	x		
Kiln climate control	Dry bulb air temperature	On/off					
		Proportional					
		PID[q]	x	x	x	x	x
	Location of dry bulb air measurement	At entry	x	x	x	x	x
		At exit	x	x	x	x	x
		Entry-exit average		x	x	x	x
	Air hygrometry – addition of water or steam	On/off	x		x		
		proportional				x	
		PID		x			x
	Air hygrometry – vent-outside air mix	On/off					
		Proportional				x	
		PID	x	x	x		x
	Location of air hygrometry measurement	At entry	x		x		
		At exit	x			x	
		At both points					x
	Number of regulated areas				4	24	12

A PID control loop regulates air temperature, as shown in Figure 3. The loop includes temperature measurement, a comparison of measurements and, depending on the observed error, a correcting system to raise or lower output from the heating source. Most manufacturers offer measurements that are taken at the lumber stack entry point or exit point or are based on an average

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[q] PID regulators are a means of modulating the opening and shutting of taps and valves on the basis of the observed control variable error resulting from a comparison of the set-point and the measured value.

of the two.[13] Steam and water injection systems are regulated by a PID or on/off taps.

In short, products available from the various manufacturers for controlling kiln air conditions are fairly comparable.

3.2.1 Setting up Drying Programs

The means used to set up drying programs is a key function[14] of kiln controllers (see Figure 3).

Table 3. Description of manufacturers' proposed means of setting up kiln programs

Manufacturers			**CATHILD Inc.**	**MEC Technology Inc.**	**Coe Manufacturing**	**Salton Fabrication Ltd.**	**Secovac Inc.**
Measurements generating drying program sequencing changes (schedule)	Air	Dry bulb air temperature	x	x	x	x	x
		Air hygrometry (air humidity)		x		x	x
		TDAL		x		x	x
	Lumber	Weight			x		
		Lumber humidity probes	x		x		x
		Other		Accudry		TCS	Accudry
		Time					
Automatic stop		Means	**Probes**	**All**	**Weights and probes**	**TCS TDAL**	**TDAL or Accudry**

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[13] The drying program must factor in the air temperature measurement location because that temperature is usually higher at the stack entry point. Measurement location changes adjustments to the controller parameters. System inertia is not the same for measurements taken at the entry and exit points. Fluctuations are reduced at the exit point, and this is reflected in the regulator PID parameter adjustments. Note also that the dynamics of the system are in flux throughout the drying process, so parameter adjustment is the compromise solution. In addition, humidity control changes air temperature and vice versa. In these conditions, air temperature and humidity often fluctuate around the set-point instead of maintaining a stable value. Manufacturers often introduce a filter for this measurement, which is why a stable value is displayed on the screens. Another point is that regulator parameter adjustments change with the heating source.

[14] See Appendix E: Main Control Systems.

The operator is responsible for determining all the stages of air temperature settings for drying. This sequencing makes up the drying program as such, and the controller will set the program up automatically.

Manufacturers offer a variety of tools for moving from one stage to the next in the drying program. They involve measuring one or more process variables; when a target value is reached, the controller changes the temperatures in the kiln. Table 3 shows the process variables used by the different manufacturers, which involve air, lumber and time measurements. Air measurement gives temperature or humidity values or differences in temperatures at the lumber stack entry and exit points (TDAL). Lumber measurements yield part-load weight values or humidity values for individual sawn lumber units. Time interval measurements are also used.

There are two approaches to setting up drying programs. The first, using measurements such as TDAL, lumber humidity probes, weight and time, can be used to trigger a new stage in the drying program.

Table 4. Manufacturers' instrumentation in dry kilns

Manufacturers			**CATHILD Inc.**	**Coe Manufacturing**	**MEC Technology Inc.**	**Salton Fabrication Ltd**	**Secovac Inc.**
Types of measurement instrument used in kilns	Air temperature	Thermocouple					
		RTDs	x	x	x	x	x
		Thermistors	x				
		Other					
	Hygrometry	Electronic probes		x	x	x	x
		Wet bulb	x	x	x	x	x
		Blotter					x
		Other					
	Weight	Samples					
		Weigh scale under rail			x		
	Lumber humidity	Resistance probes	x		x	x	x
		Other		x		x	x

With the second approach, air temperature or humidity can be gradually adjusted to achieve a preset drying rate. The drying rate is determined through correlations with measurements for TDAL, lumber humidity or weight. For example, the operator may want to maintain a constant TDAL value and, in order to do so, will adjust the air temperature or humidity in the kiln. The operator then assumes that the lumber is being dried at a constant rate.

A drying program can be designed on the basis of one or a combination of the above means. There are many options, depending on the measurement instruments available from the manufacturers (see Table 4). The degree of precision and location of the instruments are also important.

Table 5 summarizes a number of additional features of modern controllers. All manufacturers offer controllers that run using Windows™, but the operating system versions differ. They also offer data and kiln program performance management utilities. Some offer interfaces for calibrating measurement instruments and managing energy use.

Table 5. Other features of kiln controllers

Manufacturer	Computer platform	Annual/monthly/daily database	Instrument calibration	Energy management
CATHILD Inc.	Windows™ 98	a/m/d	No	Yes
Coe Manufacturing	Windows™	a/m/d	Yes	Yes
MEC Technology Inc.	PLC and Windows™ 2000	a/m/d	Yes	Yes
Salton Fabrication Ltd.	Windows™	a/m/d	Yes	Yes
Secovac Inc.	Windows™	a/m/d	Yes	Yes

In conclusion, the differences among manufacturers are somewhat greater here than in the areas discussed earlier. The level of technology, however, is the same. Drying programs are still the operators’ responsibility, and proper drying operations depend on their know-how.

4 Review of R&D on Dry Kiln Control

In this section we review a number of scientific and technical developments in lumber drying. Specifically, we look at R&D on new measurement instruments and mathematical models that relate to kiln controller development.

Research on measurement instruments focuses on process measurement tools for triggering a new stage in the drying program and accurately determining the kiln stop point. Research on mathematical models focuses on ways to set drying programs automatically. Our sources were leading scientific journals and the Internet.

4.1 Kiln Instrumentation

The following factors affect drying quality: moisture content, moisture gradient in sawn lumber units, and limitations imposed by moisture content variations in individual lumber units. These variables are difficult to measure and therefore present a challenge to instrument developers.

Today, two types of measurement are required when operating drying programs. The first is measurements of change in moisture content, which serves mainly to trigger a new stage in the drying program; the second is measurement of the moisture content of the load, which serves to determine when the kilns are to be shut off.

Measurement instruments are difficult to develop because of varying wood properties, the large number of individual units in the kiln, variable drying conditions, the technical difficulties involved in measuring high and low moisture content, and working conditions in an industrial environment.

Table 6 lists the leading measurement instrument manufacturers for the industry and published research projects. We make no distinction between research for the hardwood industry and research for the softwood industry because the measurement problem is, in our opinion, the same in the two sectors. Note also that some of the instruments in Table 6 are already operational; others are only prototypes.

Table 6. Manufacturers and prototypes of measurement instruments for drying

Manufacturer/ Developer	Technology	Validity range	Measurement variable	No. of measurement points	Stop/Sequence function	Commercial product or R&D
Jim Fuller[t]	Surface mechanical movement	30–0%	Constant	Units	Stop and sequence	R&D turning into commercial product
Accudry (AEM Corporation)[u]	Dielectric properties of wood	150–3%	Dielectric properties correlated with moisture content	Units	Stop and sequence	Commercial product
Wellons Inc.[v]	Dielectric properties of wood	Above and below fibre saturation point	Dielectric properties correlated with MC	Bundle	Stop and sequence	Commercial product
Windsor Engineering Group[w]	Dielectric properties of wood	Above and below fibre saturation point	Dielectric properties correlated with MC	Bundles /area	Stop and sequence	Commercial product
Lignomat[x]	Wireless electrical resistance	MC 100 – 2.5% EMC 28 – 2%	Dielectric properties correlated with MC	32 measurements per transmitter	Stop and sequence	Commercial product

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[t] Fuller, J., 2002: Stress-Based Kiln Monitor/Control: Concept and Industrial Trial, Quality Drying: The Key to Profitable Manufacturing, Conference Proceedings, pp. 73-77, Forest Products Society.

[u] Kiln Moisture Measurement – Accudry – from Applied Engineering Management Corp., Manufacturing Division, 14030 Thunderbolt Place, #900, Chantilly, Virginia 22033, USA, Tel.: 1 877 DIAL-AEM, Web site: www.secovac.com/Index_e.html.

[v] The Capacitance Moisture Meter System, from Wellons Inc., PO Box 1030, Sherwood, Oregon 97140, USA, Tel.: (503) 625-6131, Web site: wellons.com.

[w] Setting the Standards for Others to Follow: Kiln Control Systems, from Windsor Engineering Group Limited, PO Box 13348, Johnsonville, Wellington, New Zealand, Tel.: 04-232-8080, Fax: 04-232-5929, e-mail: wg-sales@windsor.co.nz.

[x] Wireless Probes Revolutionize Moisture Measurement When Drying, from Lignomat USA Ltd., 14345 NE Morris Court, Portland, Oregon 97230 USA, Tel.: 1 800 227-2105, Fax: (503) 255-1430; Web site: www.lignomatusa.com/wirelss.htm.

Manufacturer/ Developer	**Technology**	**Validity range**	**Measurement variable**	**No. of measurement points**	**Stop/Sequence function**	**Commercial product or R&D**
Frank C. Beal et al.[y]	Acoustic emission	N/A	Acoustic emission correlated with lumber stress	N/A	Stop and sequence	R&D
Manufacturer/Developer	Technology	Validity range	Measurement variable	No. of measurement points	Stop /Sequence function	Commercial product or R&D
François S. Malan and Kemal Ahmet[z]	Microwave frequency 1 GHz	N/A	Wave speed correlated with MC	N/A	Stop	R&D
Jonathan Hood, Audimar Bangi, Perry N. Peralta[aa]	Surface heat flux	Above and below fibre saturation point	Heat flux correlated with MC	N/A	Stop and sequence	R&D

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[y] Frank C. Beal et al., 2002: Hardwood Drying Control Using Acoustic Emission Technology, Quality Drying: The Key to Profitable Manufacturing, Conference Proceedings, pp. 77-85, Forest Products Society.

[z] François S. Malan and Kemal Ahmet, 2002: Moisture Measurement in Wood with a 1 GHz Transmission Line Probe, Quality Drying: The Key to Profitable Manufacturing, Conference Proceedings, pp. 127-133, Forest Products Society.

[aa] Jonathan Hood, Audimar Bangi and Perry N. Peralta, 2002: Monitoring the Lumber Drying Process Using a Heat Flux Transducer, Forest Products Society, 56th Annual Meeting (www.forestprod.org/am02abs.pdf).

Manufacturer/Developer	Technology	Validity range	Measurement variable	No. of measurement points	Stop/Sequence function	Commercial product or R&D
Perceptron Inc.[bb]	Acoustic emission	Above and below fibre saturation point	Speed of sound correlated with MC and acoustic emissions correlated with lumber stress	N/	Sd sence	R&D
Little, weigh scale in kilns[cc]						

Values in Table 6 are generated from a compilation of data in publicly available advertising and technical documents. This table helps to highlight trends in the development of instrumentation for the lumber-drying industry.

4.2 Mathematical Models of Lumber Drying

Research projects on modelling the lumber-drying process are many and varied. In the following we give an overview of research activities, with specific reference to work on kiln control. The development of mathematical models responds to the need for tools that set and run drying programs. As already stated, operators are still responsible for setting and running the programs, so the goal is to integrate the models into kiln controls and thus develop new, advanced controllers.

[bb] Integrated Acoustic Kiln Monitor to Guide Accelerated Drying of Wood, from Perceptron Inc., Ultrasound Technology Group, PO Box 825, Spring House, Pennsylvania 19477-0825 USA, Tel.: (215) 641-4909, Fax: (215) 641-9254, Web sites: www.perceptron.com and www.oit.doc.org

[cc] Little, R., 1996: An Automated Weight-Based System for Kiln Control, 5th International IUFRO Wood Drying Conference, “Quality Wood Drying Through Process Modelling and Novel Technologies,” Proceedings, pp. 261-269.

In summarizing current research, we have divided the models into three categories reflecting the three stages that, in our view, are pre-requisites for the integration of mathematical models into dry kiln control systems. The categories are :

1. models that describe response of lumber to drying
2. models that target optimum changes in lumber moisture content
3. models for automatic activation of optimum drying

4.2.1 Models that Describe the Response of Lumber to Drying

The purpose of the first category of models is to aid in visualizing the drying process by generating curves that show changes in lumber moisture content. This helps in understanding the drying process and in predicting performance according to a variety of air conditions and wood characteristics. They can be used to predict lumber response during drying and help the operator develop drying programs.

The category covers a large percentage of modelling activities. One of the first models[ee] was presented by Bramhall in 1979[ff]. The author did not claim to cover all aspects of the drying process with the model, and indeed, a number of researchers have focused on developing other models since then[gg]. Because wood properties are naturally variable, there is still no universal model. The conclusion drawn by Kamke and Vanek in their comparative study[hh] of several published research models is that there are a number of models that have limited validity ranges.

Their study highlighted major differences among the models, and most of the simulation results did not match the experimental trial results. The low correlation between simulations and experiments explains why operators do not always use models to set drying programs and upgrade the drying operation.

[ee] One of the most complete, in our opinion.

[ff] Bramhall, G., 1979: Mathematical Model for Lumber Drying. I. Principles Involved. II. The Model. Wood Science, Vol. 12, pp. 14-31.

[gg] The basic models describe changes in wood moisture content from a set of equations determining mass and energy totals. In all cases, initial wood moisture content (starting condition) and drying conditions at wood surface (frontier conditions) must be known. They differ from one another in the selection of laws that govern the movement of water in the wood, the number of directions of movement studied, digital resolution methods, and means of expressing drying conditions at the surface of the wood.

[hh] Kamke, F. A., and Vanek, M.: Comparison of Wood Drying Models, 4th IUFRO International Wood Drying Conference, Rotura, New Zealand, 1994, pp. 1-21, Keynote Address.

Because the variability of wood and the drying process is a significant limitation in modelling, some authors have focused on it. Kayihan[ii] developed a model that is often cited. He examined the stochastic aspect of the process, noting that with such an approach each simulation must generate slightly different results. As would be the case for an actual kiln, each piece of lumber has distinct properties and is subjected to different drying conditions depending on its position in the stack. This type of model brings out the variability aspects of the process and, in our view, provides a solid basis for optimizing and applying controls to the lumber-drying process. Cronin[jj] also recently examined the probabilistic aspects of the lumber-drying process. In theory, a statistical approach should prove effective in generating a picture of the natural variability of the process.

4.2.2 Models that Target Optimum Changes in Lumber Moisture Content

If the models in the first category proved to be accurate, a natural development would be to devise optimization methods that would set drying programs by calculating changes in optimum wood moisture content. Such methods constitute the second category of models.

Broadly speaking, optimization may be defined as follows: determining the change in wood moisture content that would minimize drying time, the number of rejects and energy use. Different tree species and drying processes would generate different optimum solutions. In the case of hardwood drying, for example, rejection because of warping, checking and splitting is of great importance and is therefore the primary optimization criterion. This would not necessarily be the case for softwood drying; in this case, time could be the prime criterion, although grade reduction and reject rate would not be ignored completely.

Accordingly, some authors[kk] have developed optimization methods for generating drying programs that would limit the number of rejects. Air temperature conditions would be adjusted to limit lumber stress and thus enhance drying quality. This approach requires adding another model to represent internal efforts generated by lumber removal, which differs from layer to layer in the stack during the drying process.

[ii] Kayihan, F., 1993: Adaptive control of stochastic batch dry kilns. Computer and Chemical Engineering, 17(3), pp. 265-273.

[jj] Cronin, K., Abodayeh, K., and Caro-Corrales, J, 2002: Probabilistic analysis and design of the industrial lumber drying process. Drying Technology, 20(2), pp. 307-324.

[kk] Lessard, R. A., Limbert, D. E., Pokoski, J. L., Hill, J. L., 1982: A stress model for lumber drying control. Journal of Dynamic Systems, Measurement and Control, Dec., Vol. 104, pp. 283-289.

Apart from these examples that focus on lumber stress, few projects[ll] have dealt with optimized drying programs. Again, this is because mathematical models cannot represent the drying process with sufficient precision and accuracy, so applying optimization methods is problematic.

4.2.3 Models for Automatic Activation of Optimum Drying

Models in the third category are designed to solve a set of equations and generate real-time estimates of specific parameters for establishing drying conditions in the kiln.

A number of authors have worked on this type,[mm] with some taking the basic models as a starting point and others exploring the avenues opened up by "fuzzy logic." In this type of application, the structure of the models is different. There are a variety of models, including identification, observation, prediction and optimization models. They also require in-kiln real-time measurements and must act directly on the process. They become an integral part of the control structure and would substantially change the existing structure, as shown in Figure 1.

Mathematical models have not produced solutions or breakthroughs in lumber-drying methods. This lack of success is not due to lack of effort, judging from the number of scientific publications on the subject. As with instrumentation, the large number of units in the kiln, the drying process and other factors limit how the models can be applied.

After more than 20 years of effort, it is easy to understand manufacturers' business decision not to become involved in R&D programs to develop new, advanced controllers. It would be difficult to justify investing in the research without having identified a promising approach with limited risk. As a result, mathematical models are still being worked on in the scientific community, although there have been a few industrial breakthroughs regarding operator training.[nn]

[ll] Rensi, G., and Weintraub, A., 1988: Using dynamic programming to obtain efficient kiln-drying schedules. Wood and Fiber Science, 20(2), pp. 215-225.

[mm] For example, Steczowicz, M., 1986: Discrete optimal control of the lumber drying process. Automatic control of continuous process. IFAC Automatic Measurement in Woodworking Industry, Bratislava, Czechoslovakia, pp. 155-158.

[nn] For example, Drytek is a software program developed by Forintek Canada Corp. to help the operator evaluate various strategies; it is used in the softwood-drying industry.

5 Present State of Drying Practices in Eastern Canada

In 2002, members of the Quebec Lumber Manufacturers' Association conducted a survey. The aim was to identify the role of operators in drying operations and their new R&D requirements for practice upgrading.

5.1 Method

The data presented in the following sections were taken from the questionnaires completed by 73 respondents. A total of 120 questionnaires were sent out, mostly to companies in Quebec and some to New Brunswick. The questions asked about the level of technology in the mills, drying technologies, practices in the lumberyard before and after drying, and general practices.

The questionnaire was designed for drying operators, quality controllers and drying operation supervisors. To increase the response rate, the 67 questions were to be answered immediately, without respondents relying on archived data or compilations. The questionnaire was sent by regular mail, and a reminder was also sent out.

5.2 Survey Highlights

- Industry opinion is that its facilities are sufficiently modern to meet current market needs.
- Industry opinion is that quality (grade reduction / rejection rate) is the most significant factor when evaluating drying systems.
- Because it is not easy to measure the quality of the drying process, drying time is most often used to evaluate drying performance.
- Although quality was identified as the main variable in the drying process, the proportion of under-dried and over-dried lumber units was 9 and 16 percent, respectively.
- Operators play a significant role in drying operations (they manage the process before, during and after drying), and their actions affect the results of the process considerably.
- The decision to purchase a drying control system is driven more by the acquisition of a kiln than by the requirements of the process itself.

5.3 Results – Eastern Canada

Survey results are presented in two sections. The first covers yard practices before and after drying. The second covers operations in the kiln. Figure 4 shows the links between the results.

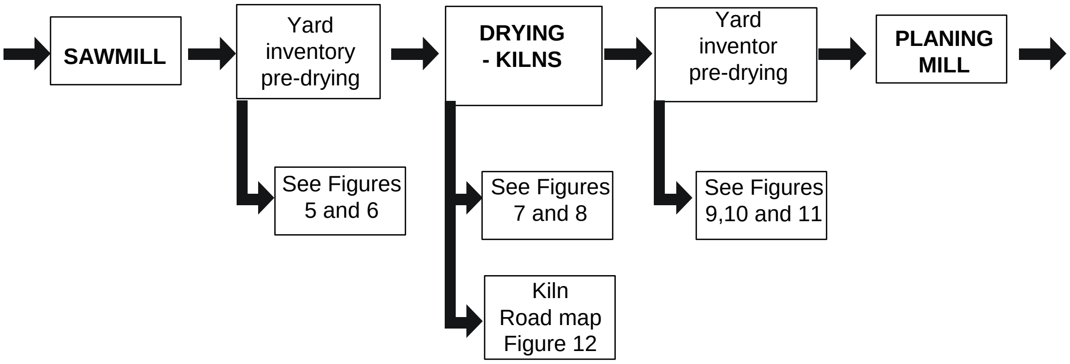


Figure 4. Road map of survey results

5.3.1 Drying Practices in Yard

The results are for practices in the yard before drying, in the kilns, and in the yard after drying.

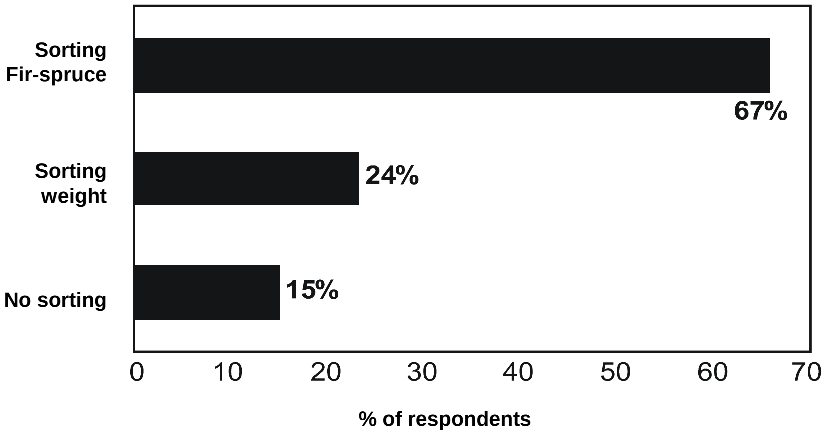


Figure 5. Sorting before drying

Before drying, mills often sort lumber by weight or species to reduce variations in moisture content in the load. Figure 5 gives the breakdown of respondents by sorting operation. It shows that 67 percent of respondents separate fir and spruce. Fir sorting is usually done manually, which works better than other less costly methods, such as sorting by weight. Weighing is done automatically, and the technology is used in 24 percent of the sites that responded to the survey. Sometimes both methods are used at the same site. Sorting is a widespread practice, although mills whose lumber supply is essentially one species do not have to sort.

Figure 6 shows how and why mills tie bundles before drying. A total of 54 percent of respondents said that they do so to reduce unit losses during bundle handling in the yard.

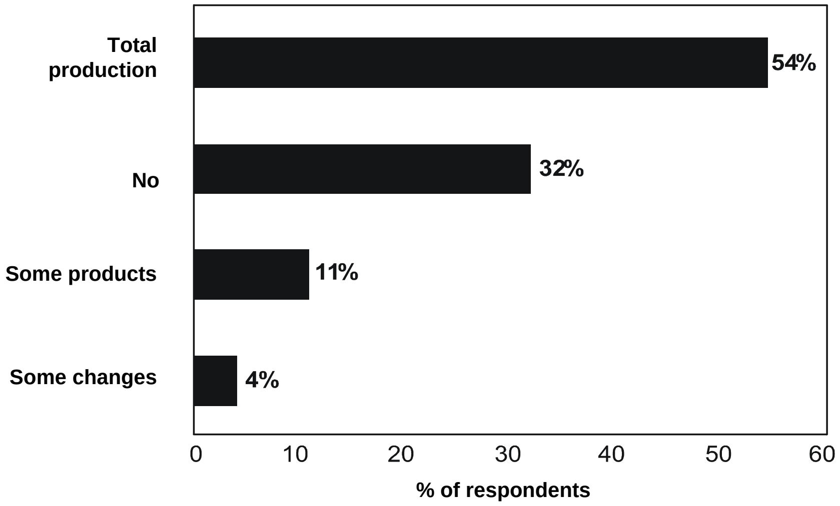


Figure 6. Are bundles tied in yard before drying?

Another common practice worth noting is that 63 percent of respondents indicated that they dry balsam fir mainly in the open air.

Figure 7 shows the average breakdown of operators’ work time by task. Management of the yard and heating systems takes up 50 percent of their time. Setting drying programs and instrumentation and supervising the drying process account for only 17 percent on average.

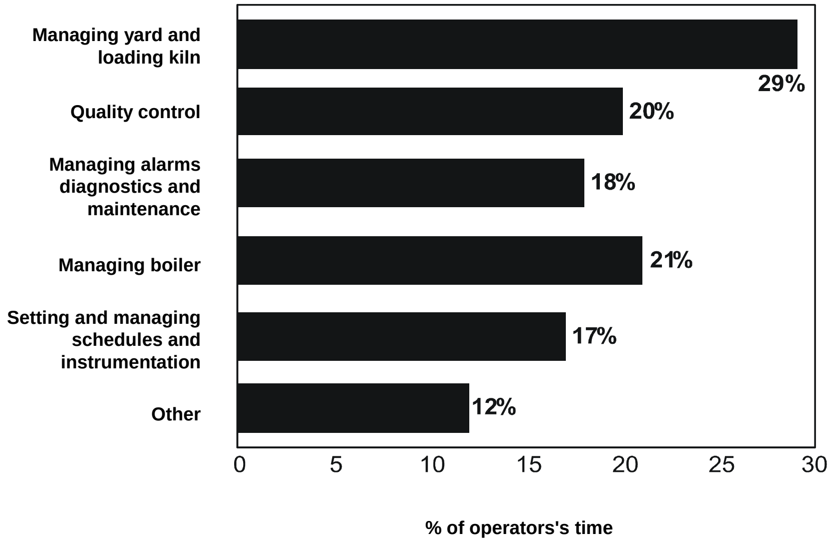


Figure 7. Breakdown of operator’s time by task

We also asked respondents what should be the focus of R&D efforts. They identified kiln controllers as the priority, followed by quality control methods. They also expressed a need for planning and managing the lumberyard.

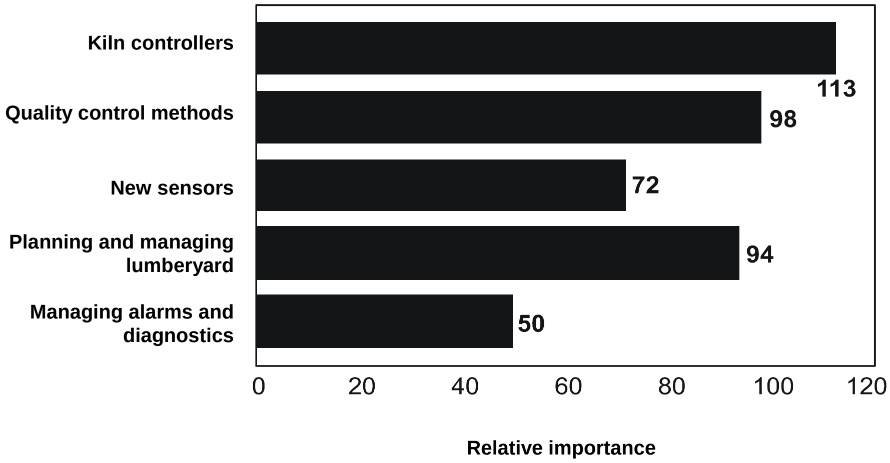


Figure 8. R&D needs expressed by industry

Figures 9, 10 and 11 show results for post-drying operations. Although quality control was identified as the most important variable, respondents indicated that 16 percent of production is over-dried and 9 percent is under-dried. Figure 9 shows the percentage of respondents that had observed specific proportions of over-dried and under-dried production.

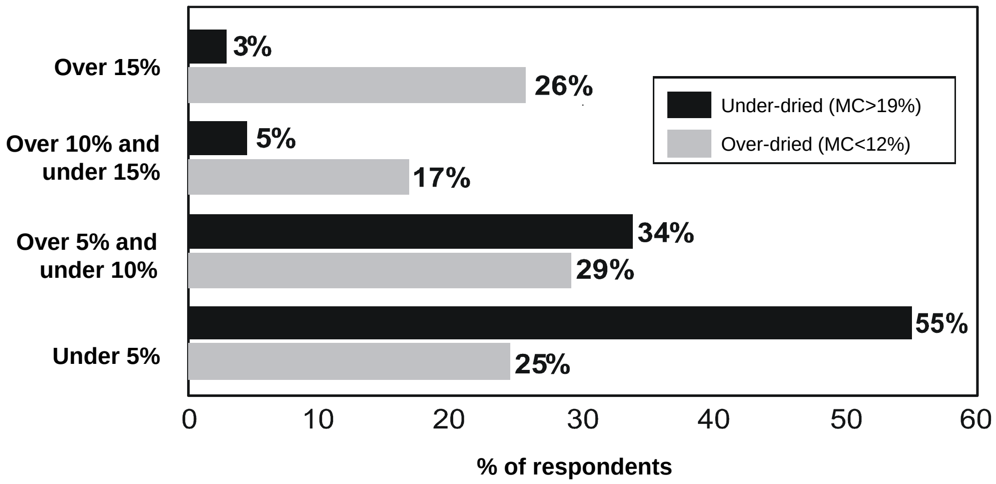


Figure 9. Percentages of under-dried and over-dried production

Figure 10 gives respondents' evaluations of drying performance. In practice, drying time is still the most used criterion.

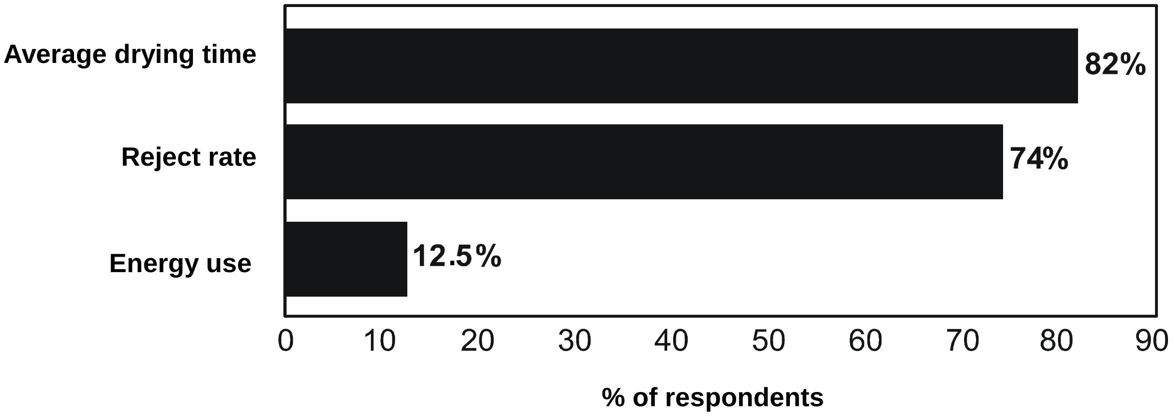


Figure 10. Drying performance evaluation criteria

Figure 11 shows the frequency of drying operation evaluations. The results suggest that some companies should conduct evaluations more often.

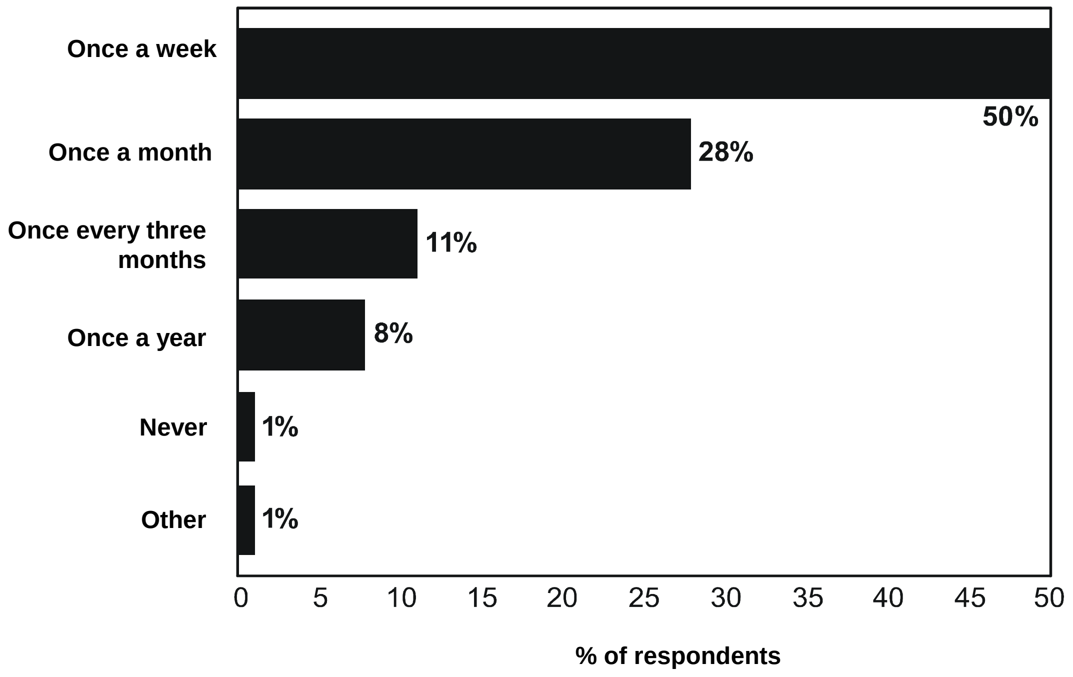


Figure 11. Performance evaluation frequency

5.3.2 Drying Practices in Kilns

The second section of the survey was on kilns. Questions were designed on the basis of the road map shown in Figure 12.

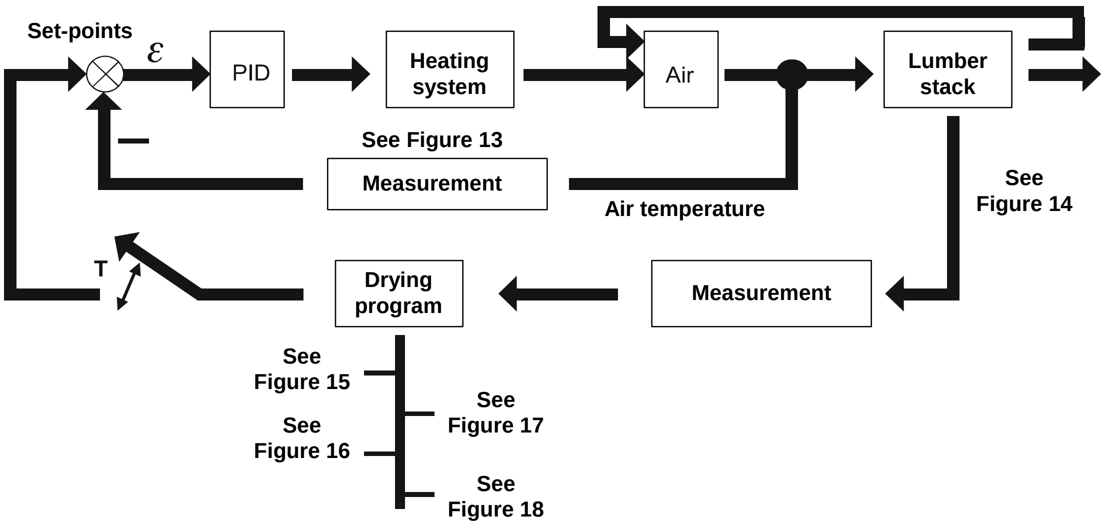


Figure 12. Road map of drying process in kilns

Instrument calibration is obviously a good way of ensuring that kilns work properly. Figure 13 indicates the number of times that drying-process supervisors calibrate their instruments. We have already noted the importance of measurement instruments that ensure that the air conditions set by the drying program are created.

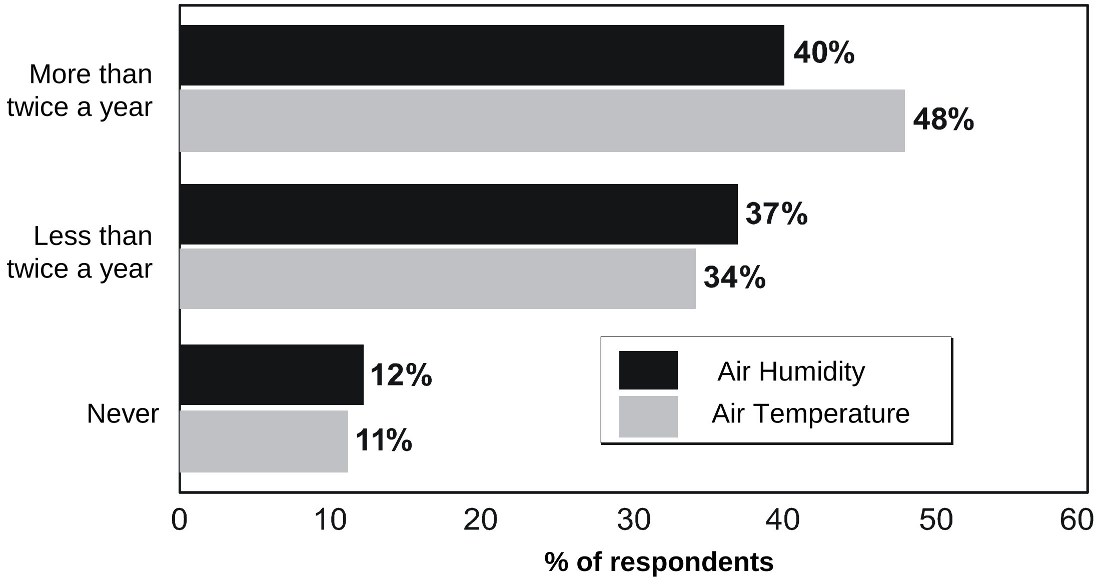


Figure 13. Frequency of calibrating measurement instruments in kilns

Figure 14 shows that, in most programs, time is still the method most often used to move to the next drying stage. As mentioned earlier, manufacturers differ in the methods used to advance the drying program through the different stages. This is why utilization percentages for the various methods correspond closely to manufacturers’ market shares.

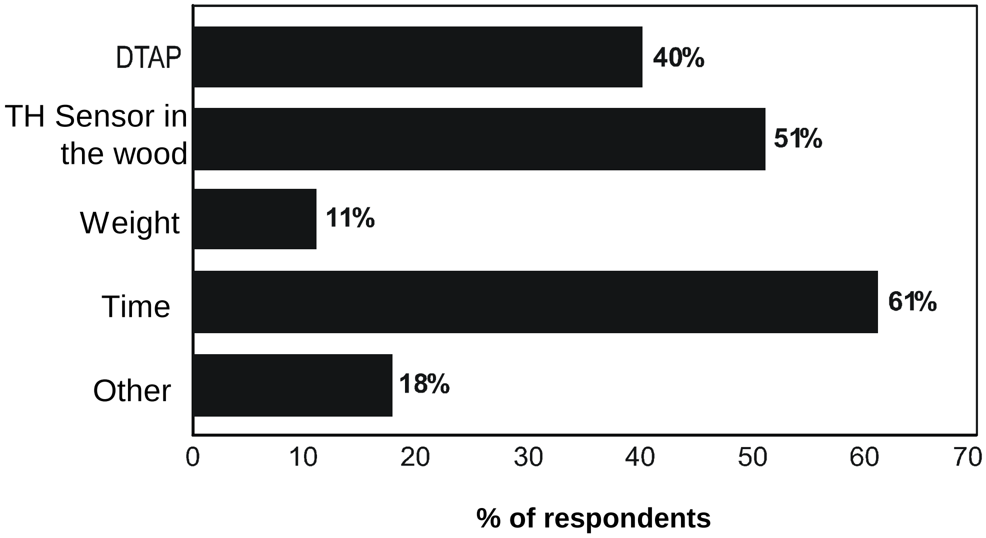


Figure 14. Methods used to advance drying program through drying sequence

Figure 15 shows that air temperature is the variable in the drying program that operators change most often. Humidity and duration of condition are used almost as much; changing air speed is not used very much.

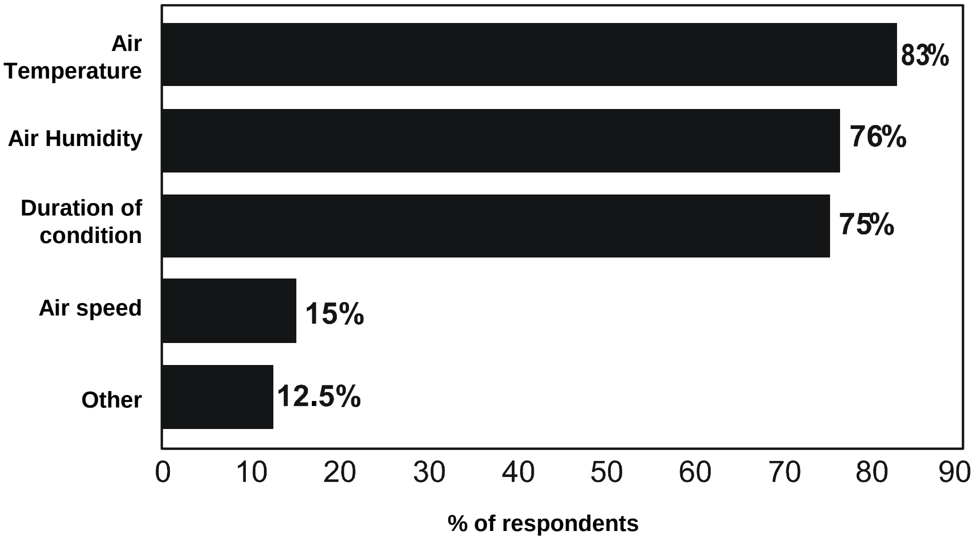


Figure 15. Types of changes made to drying programs by operators

Figure 16 outlines factors that trigger changes to drying programs.

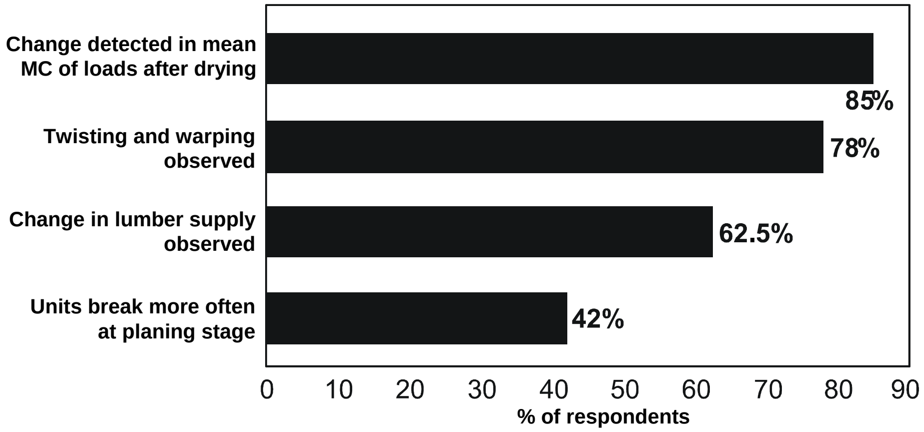


Figure 16. Factors that trigger changes to drying programs

Figure 17 shows that changing tree species requires a new program to be activated. This is also related to the fact that the sorting by species is a widespread practice (see Figure 5). That being said, there is a wide variety of drying programs at each mill. Figure 17 lists reasons given by a number of operators.

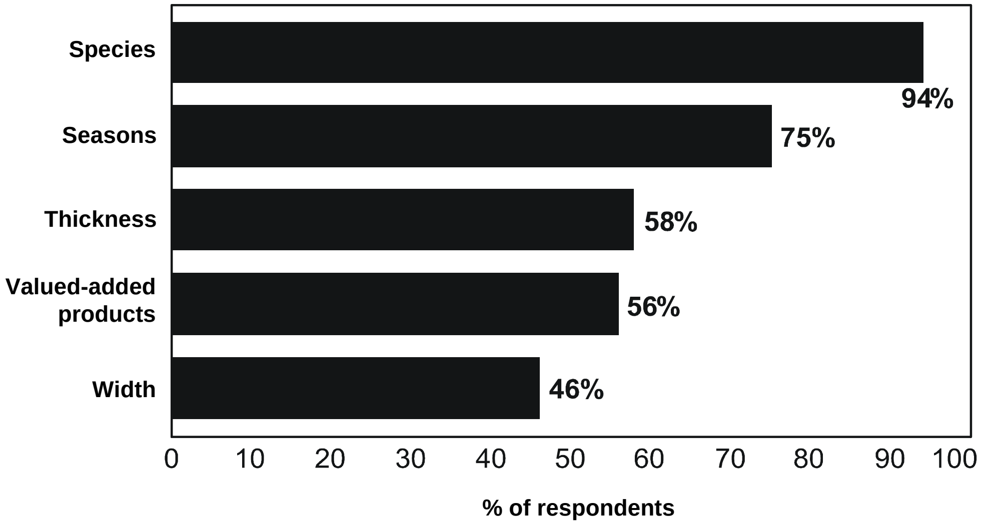


Figure 17. Reasons for setting a new drying program

Figure 18 outlines reasons for making changes to drying programs. Changing seasons is the most popular reason. Note, however, that some operators change programs during the drying process. There may be two reasons for this: (1) almost half the systems are automatic; and (2) only some operators have the expertise to change a drying program.

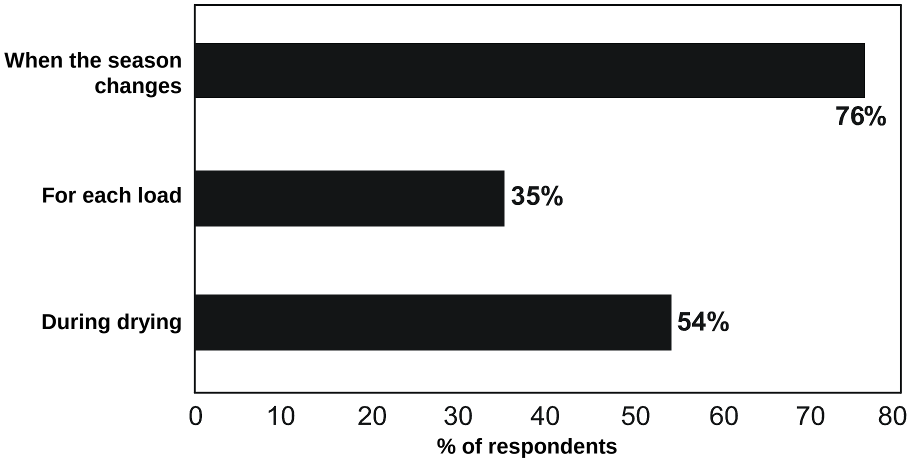


Figure 18. When are changes made to drying programs?

In short, there are many drying programs, and none seems to predominate. They are often the result of initiatives by operators, who generally do not have the means to prove the cost-effectiveness of their efforts. The situation may be partly attributable to the lack of tools for quality measurement and tracking energy costs. For example, over 80 percent of survey respondents estimated that 10 percent or more of their production fell outside the 12 to 19 percent moisture content range. Note that their identification of kiln controllers and quality control methods as research priorities is a logical response to that estimate.

6 Present State of Drying Practices in Western Canada

In 2002, an e-mail survey was conducted of companies in western Canada. In all, 65 questionnaires were sent out, and 10 were completed and returned. We will present a more concise overview of the responses from western Canada than from eastern Canada.

6.1 Results – Western Canada

6.1.1 Drying Practices in Yard

In answer to the question as to whether sorting was done before drying (see Figure 5), one third of respondents said that they sorted fir, one third said that they sorted using equipment from the manufacturer NMI, and one third said that they did not sort at all before drying.

In answer to the question as to whether bundles were tied in the yard before drying (see Figure 6), 11 percent indicated that they did so and that it applied to only part of their production.

In answer to the question on the breakdown of operators' time (see Figure 7), yard and load management takes up over 50 percent of operators' time. The balance is divided almost equally among quality control, alarm management and scheduling.

In answer to the question on R&D needs (see Figure 8), western respondents differed from their eastern counterparts. They consider yard management to be the main priority—a response consistent with their answer to the preceding question—followed by alarm management and quality control.

In answer to the question regarding over-dried and under-dried percentages (see Figure 9), respondents indicated an average of 18 percent for over-dried production and 5 percent for under-dried production.

In answer to the question on drying performance evaluation criteria (see Figure 10), respondents indicated that drying time was a performance indicator in all cases and that the rejection rate was an indicator in 80 percent of cases. It appears that the evaluation of energy use is more important in the west than in the east: 50 percent of western respondents indicated that it was a criterion

In answer to the question on frequency of performance evaluation (see Figure 11), half of the respondents said that they did so once a week; the other half said once a month.

Regarding the question on frequency of instrument calibration in kilns (see Figure 13), nearly all the respondents said that they calibrated temperature measurement instruments once a year. For air humidity measurement, one third calibrate once a month, one half do so once a year, and the rest never do.

In answer to the question on methods for advancing a drying program through the drying sequence (see Figure 14), western respondents agreed with their eastern counterparts, saying that time was the most important factor. TDAL is the second most important factor for one third of western respondents; measurement of lumber moisture content was the second most important for one quarter of them.

In answer to the question on changes made to drying programs by operators (see Figure 15), the responses were as follows: air conditions, 77 percent; air humidity, 66 percent; duration of condition, 33 percent; and air speed, 22 percent.

In answer to the question on what factors trigger changes to drying programs (see Figure 16), western respondents indicated that they were always watching for load changes and variations in moisture content at the planning stage; 70 percent said that they made scheduling changes based on reject observations.

In answer to the question on reasons for setting a new drying program (see Figure 17), all respondents said that lumber size and a change of season warranted a scheduling change, 90 percent made changes for frozen lumber, 80 percent did so for tree species, 70 percent made changes for thickness, and 50 percent changed the schedule for valued-added products.

In answer to the question on when they made changes to drying programs (see Figure 18), all respondents said that they did so when there was a change of season, 87 percent said that they did so for each loading, and 77 percent said that they made changes during the drying process.

7 Conclusion

In our study we have identified a number of technical impediments to effective control of the lumber-drying process. These include the difficulties involved in measuring lumber moisture content, the large number of sawn lumber units, and the fact that operators are still responsible for setting drying programs. The scientific community and the industry acknowledge that the development of an advanced controller could be an effective way of upgrading the drying process. The new type of controller would be designed from mathematical models for the purpose of solving some of the technical problems identified. Yet in spite of many years of effort, a high-performance controller has yet to appear. We can therefore conclude that the problems of modelling the drying process and measuring moisture content remain major barriers to introducing advanced control systems.

But these are not the only barriers. The complexity of the process is not restricted to what goes on in the kiln—it extends to the drying practices themselves and to the fact that the operator plays a major role in these practices, making many decisions on yard management before and after drying. In addition, so many variables are at play that it is difficult to establish a direct link between a change in practices and process enhancement. Another significant barrier to the development of new drying practices is the difficulty in conducting fast, precise and accurate evaluations of the financial benefits of any new practices.

Although they are not barriers as such, existing quality standards on final moisture content, variations in moisture content and moisture gradient range do nothing to stimulate development of new, advanced systems. Establishing more rigorous and precise standards will foster that development.

We have reflected on what potential applications would be beneficial to the industry. In our opinion, developing a system for monitoring the whole drying process is worth exploring. Such a system would collect all the data generated by measurement instruments in all areas, from the sawmill to the planing mill. It would make it possible to establish productivity and quality indicators for calculating the monetary value of operators' enhancements to the process and to identify and provide a rationale for other promising avenues of research.

Collecting process-generated data would yield very large databases. It would then be possible to apply multivariate analyses. These tools are increasingly proving their worth in industry. In Canada, for instance, the steel and pulp and paper industries have had success with them. They synthesize data from all the different measurements in the form of models, which can then be used to predict system behaviour. Because of the statistical approach built into these tools, they should be compatible with the lumber-drying process.

Process monitoring should also lead to the application of experimental design methods in identifying process enhancement. This would involve programming variations in specific system entry variables on the basis of a preset strategy and observing the results. With data from a few trials, it is possible to extrapolate a more effective and efficient drying process. Without the database created from the monitoring system, implementing experimental design approaches would be very complicated and expensive.

This approach would make it possible to enhance control of the drying process and process quality while also revealing potential energy savings.

Appendix A
Kilns and their Environment

Kilns and their Environment

A1 Dry Kiln

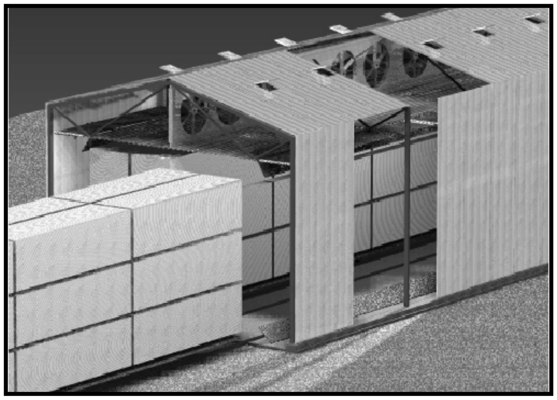


Figure A-1. Dry kiln

A dry kiln is an industrial building in which appropriate conditions can be maintained for drying lumber. The form and construction are designed to supply and control air temperature, humidity and circulation. This is why most modern kilns are made of insulation panels. Inside the kiln are fans, heating and humidification systems and vents. There have been few innovations in kiln construction in recent years. The kiln operates by batch loading: the load does not move during the drying process, but the drying conditions change in accordance with a preset drying program.

The quality of kiln design affects drying performance. With regard to energy efficiency, the kiln must be well insulated in order to reduce demand for power and prevent condensation on the walls. The kiln must also be airtight for better control of leaks into and out of the building. Effective control of this type cuts down on humidity variations and the need for extra humidification. Finally, heating coils and fans must be arranged and positioned in such a way as to ensure even distribution of the air and heat needed for drying. Kiln design can be an impediment to efforts to upgrade drying programs.

A2 Drying Rate

If the ambient conditions in the kiln are controlled, drying can be achieved faster. The drying rate is the indicator for measuring drying speed. Studies show that the drying rate is influenced by a variety of factors, including lumber temperature, moisture content, and the form and structure and the components of the process itself, such as ventilation and kiln design. In Figure A-2, the drying rate is expressed by the slope of the line tangent to the drying curve. The value of the drying rate equals the difference in moisture content divided by the time difference (shown by the small triangle tangent to the drying curve in Figure A-2).

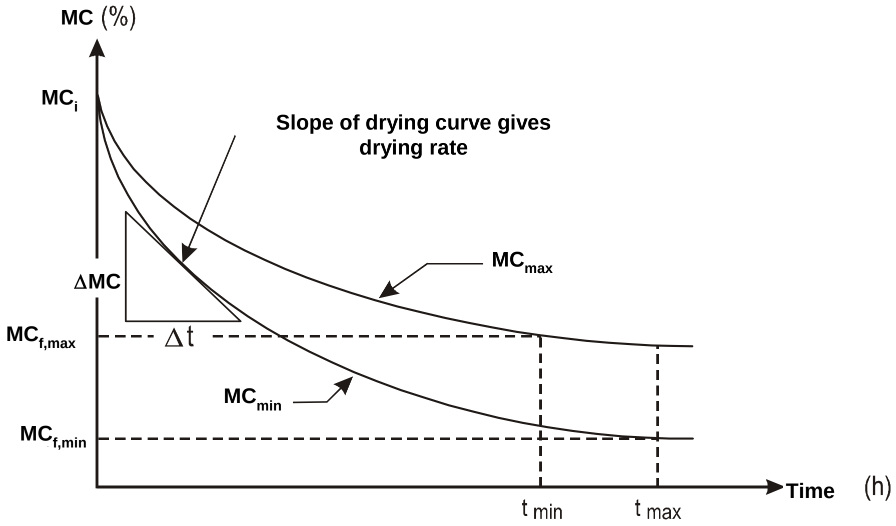


Figure A-2. Typical lumber-drying curve

Figure A-2 also shows that if the same triangle were drawn again later in the process, the slope would be gentler, and the drying rate would consequently be lower. In this second drying phase, the amount of water in the lumber has dropped and water migration to the surface of the lumber is more difficult. Thus the drying rate falls toward the end of the drying process. This is a key characteristic of the process and affects drying program settings.

There are other characteristics that influence change in lumber moisture content. These include differences in lumber structure, form, the position of sawn lumber units in the stacks and the initial moisture content. Thus the change in lumber moisture content illustrated in Figure A-3 is more representative of the modern drying process and underlies the conceptual definition of the drying process field.

A3 Drying Process Field

Change in moisture content (MC) in a lumber load may be represented as an area with upper and lower limits instead of just a curve, as shown in Figure A-3 by the set of experimental curves for drying a load of fir. This area is called the drying process field.

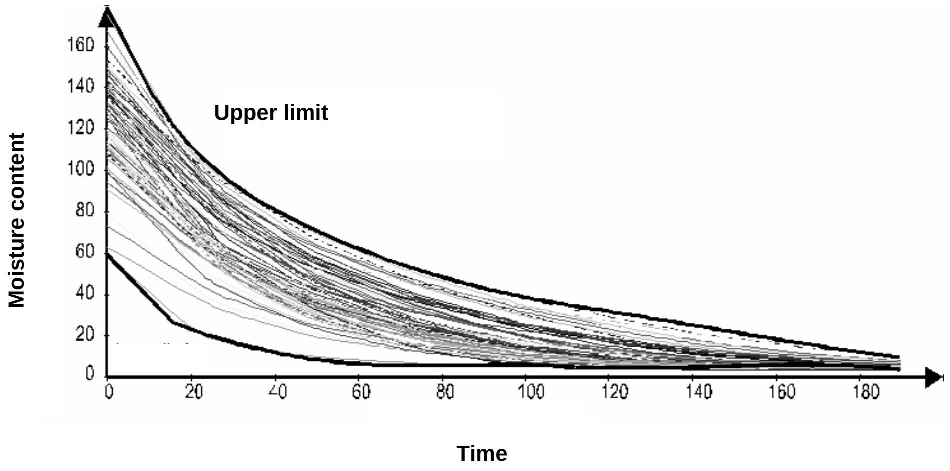


Figure A-3. Drying process field

The drying process field shown above represents the loading and method used to control MC changes. For example, different supplies of lumber would generate different drying rates. Similarly, using different drying temperatures or kiln configurations would generate different drying curves. So the process must be examined using the concept of drying process field, not just the concept of a single drying curve.

A4 Aspects of Drying

With reference to the drying process field concept, we can divide all the aspects that influence it into groups, as shown in Table A-1. They are grouped under three headings: operational, geometric and raw material.

Table A-1: Aspects of lumber-drying process

Operational
- Air temperature
- Air humidity
- Air speed
- Drying program
- Measures to move program through sequence

Geometric
- Length of airflow
- Thickness of spacers
- No. of stacks in row
- Lumber thickness and length
- Lumber grade (wane, quality, etc.)

Raw material
- Species
- Initial MC
- Density
- Origin

Table A-2: Stochastic aspect of lumber-drying process

Raw material (from tree to sized lumber)
- Stochastic distribution of initial MC
- Stochastic distribution of drying rate
- Stochastic distribution of thickness and grade

Unevenness of drying potential (caused by deteriorating air conditions in kiln)
- Changes with position in kiln
- Changes over time through program
- Batch process
- Large number of units (10^4) in batch

Quality is measured at end of drying process
- Each unit evaluated separately before sale
- Significant correlation between final MC and rejects

In addition, the preceding aspects of the process field are deterministic, and their distribution affects the size of the drying field. Thus the values must be characterized by the form of distribution, their mean value and their standard deviation. These characteristics are grouped together in Table A-2 and express the stochastic aspect of the lumber-drying process.

In conclusion, and in light of the description of the drying process, it would be erroneous to speak of a single curve in a kiln. Development of a drying strategy must factor in the drying field outlined in the preceding.

Appendix B
Additional Information on Drying Process Control

Kilns and their Environment

The challenge in kiln control is to determine optimum change in moisture content so as to obtain a final moisture content while minimizing the application of performance criteria based on reject rates, time and energy (see Figure B-1).

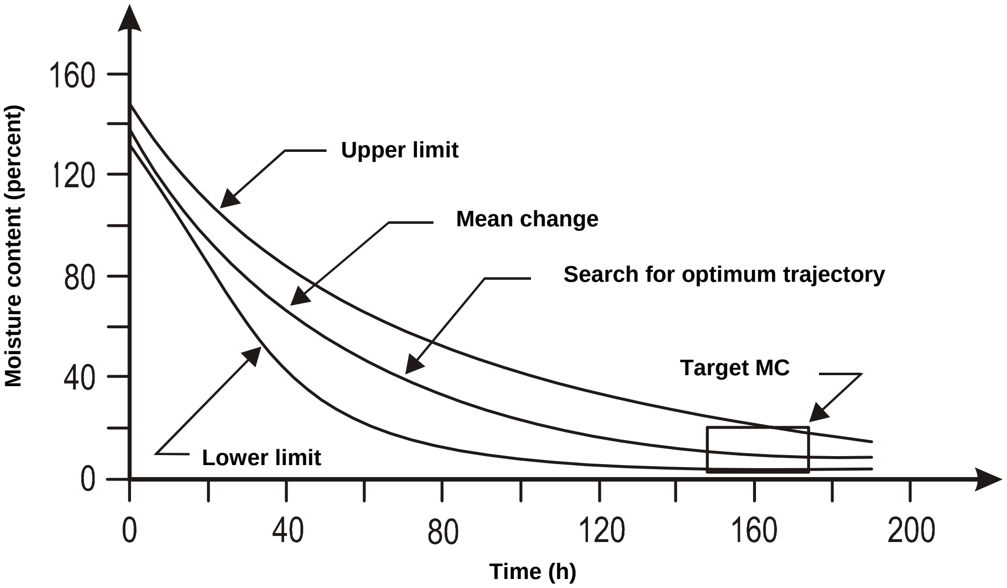


Figure B-1. Optimum profile of change in moisture content of lumber load during drying

Determining the optimum change must factor in kiln capacity and dynamics, load response, initial moisture content of the load, deterioration of air conditions as air passes through the stack, and the variability of the physical properties of each sawn lumber unit.

In automation language, this approach takes the following form (see Figure B-2), in which the kiln and its load, called the drying system, react to controller commands to force changes in moisture content following a preset optimum trajectory. Moisture content (MC) thus becomes the control variable.

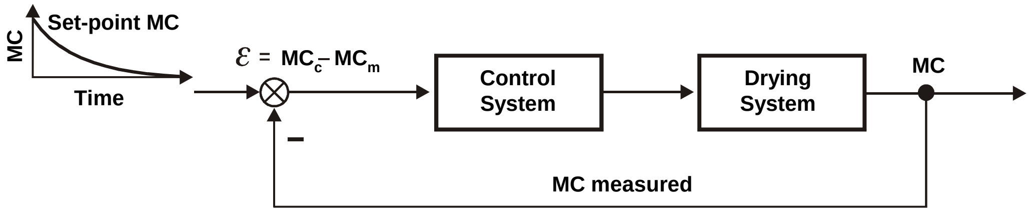


Figure B-2. Control structure with moisture content as control variable

This control system is called a closed loop control system. It would use the comparison of an output signal (in this scenario the MC measured) with a set-point value (in this case the target MC) to activate the control system to reduce the error detected.

In designing such a control system, three things must be determined. The first is the optimum change in MC, as described in the preceding. The second is the actual design of the controller. The third is a means of measuring the MC variable as a system output so that the system works.

In lumber-drying practice, all three aspects are difficult if not impossible to determine. So far, no method has been established for determining the optimum MC of a full load while factoring in reject rate, time and energy. Only a few experimental data are available for setting the curve. This situation is attributable to the difficulty experienced in trying to identify the drying load and the variability of lumber characteristics as presented in Tables A-1 and A-2.

Thus, for the control system illustrated in Figure B-2, the controller needs a comparison of the set-point and output MC values. However, it is difficult to measure MC as an output signal. MC varies from one sawn lumber unit to another and even varies within a single unit. Furthermore, it can be measured only for a limited range of MC values. It is therefore impossible to compare a measured value with the set-point value—a fact that, in the case under consideration, limits the possibility of using the control structure illustrated in Figure B-2.

In the final analysis, the direct process control variables become air temperature, speed and direction. Figure B-3 shows a simplified form of a control structure. With this structure, it is possible to measure air temperature, compare it with a set-point temperature, and then act on the process to reduce any error that is detected.

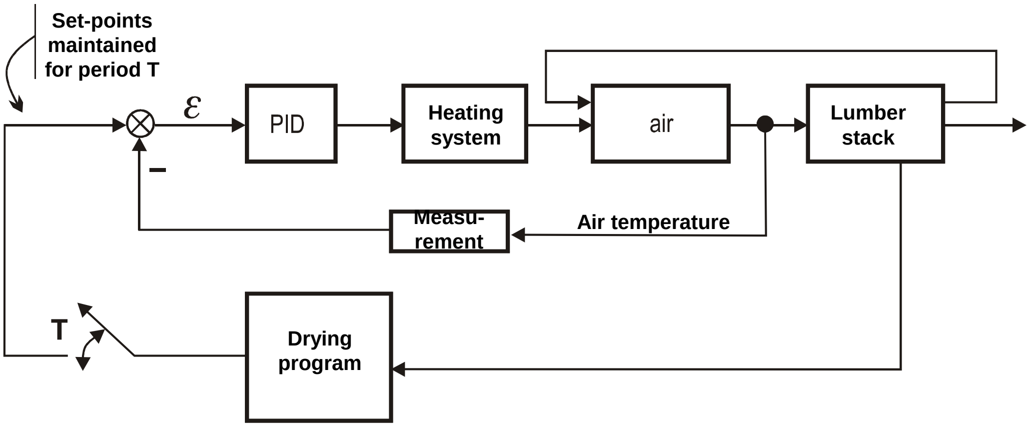


Figure B-3. Simplified block diagram of existing kiln control system

In this case, MC is still the system output but it is an estimate, which may be based on time, on a sample-generated MC value, on a TDAL measurement, or on a measurement of the variation in stack or control unit weight, etc. The estimated value will determine when to move to the next stage in the drying program. In this way, new air temperature settings are activated throughout the drying process.

Thus control of the drying process is undertaken by a sequencer system. The output, i.e., the change in MC, exerts no direct effect on control except to activate the next stage in the drying program. For this reason, any disturbance that is specific to the drying process will not be detected by the control system and will not trigger any change in the program. As a result, application of the open loop control system in practice limits the potential for automation enhancement to the drying process.

In these conditions, setting and implementing a drying program raises other difficulties. Operators set and adjust programs without the benefit of the right tools. Trial and error is the usual approach. Operators go through a cycle, setting and adjusting the program, drying the load and checking the results (Figure B-4). They then determine where enhancements can be made and change the program accordingly.

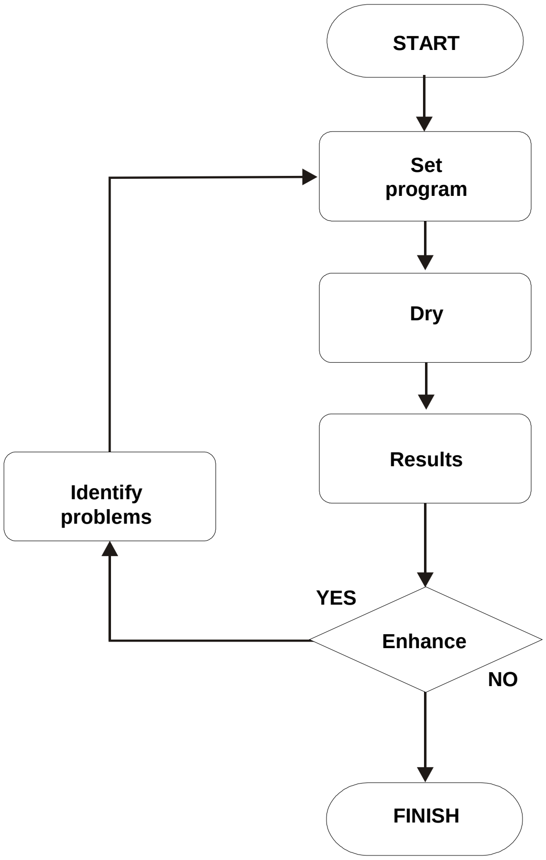


Figure B-4. Algorithm for modifying drying program

Operators have limited means at their disposal. They can act by changing operating temperatures or by finding new measurement instruments for determining the precise time for the program to change conditions. Figure B-5 illustrates these types of actions. During drying, enhancements are made principally on the vertical lines of the drying program. Movement of the vertical lines indicates a search for a better time to change temperatures in the kiln. The horizontal lines generally move when the program is being set before drying, on the basis of earlier results. The movement should be effected only when the operator has a clear understanding of the physical phenomena driving the drying process.

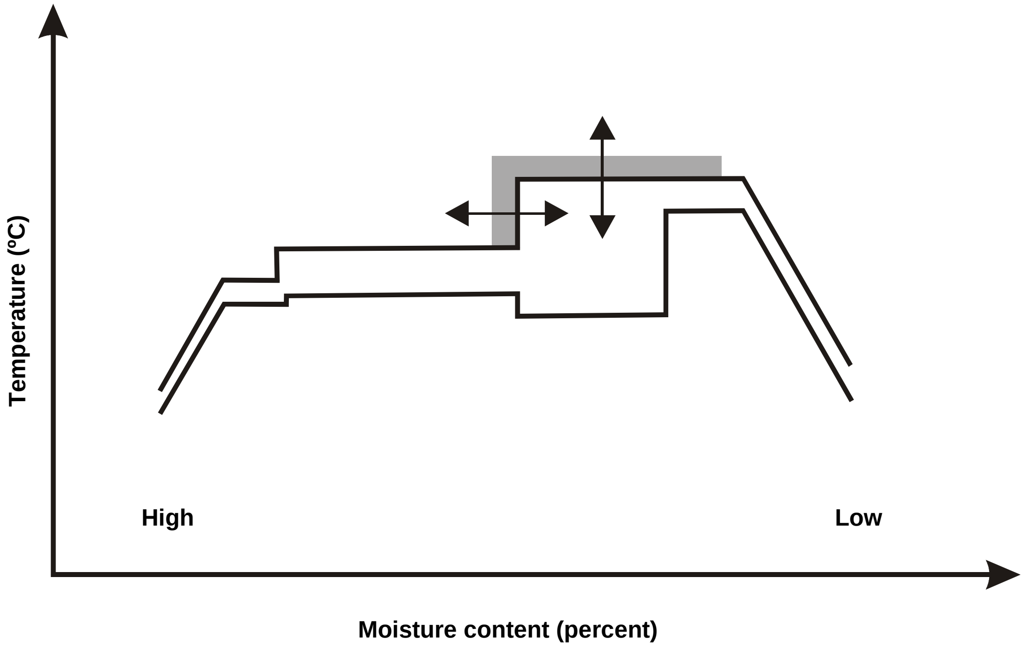


Figure B-5. Modifiable stages of drying program

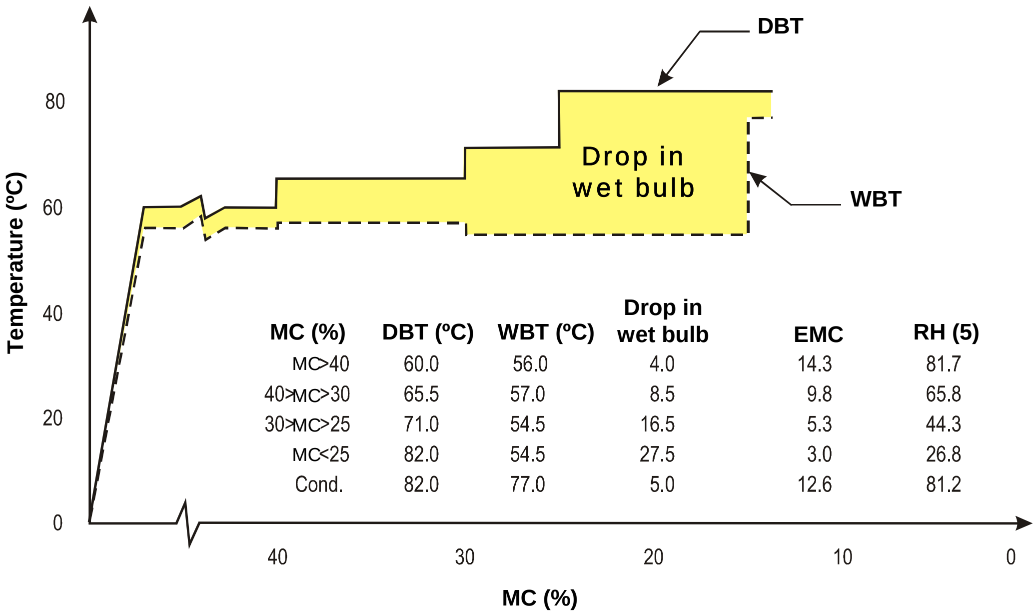
Appendix C
Dry Kiln Control Structure

Dry Kiln Control Structure

C1 Setting a Drying Program

Lumber is dried through the transfer of heat and mass between the air and the lumber. Enough is known about air-lumber relationships to be able to determine the air conditions suitable for drying. This explains why kiln control systems act directly on air temperature, humidity and speed.

On a day-to-day basis, an experienced operator can modify a drying program using the parameters listed in Tables A-1 and A-2. Figure C-1 shows the form of a typical basic program. The operator can analyse a variety of strategies such as the impact of sorting, the effect of changes to the geometric configuration of loads, and variations in the methods of measuring load moisture content.



MC (%)	DBT (°C)	WBT (°C)	Drop in wet bulb	EMC	RH (5)
MC>40	60.0	56.0	4.0	14.3	81.7
40>MC>30	65.5	57.0	8.5	9.8	65.8
30>MC>25	71.0	54.5	16.5	5.3	44.3
MC<25	82.0	54.5	27.5	3.0	26.8
Cond.	82.0	77.0	5.0	12.6	81.2

Figure C-1. Black spruce–drying program

To segment a program properly into stages and set operating temperatures, operators must have a clear understanding of each stage in the program. Some stages depend on the process itself, while others are related to lumber response during drying.

The first stage in a drying program is the rise in lumber temperature. The kiln, the air and the lumber have to be heated up. In winter, this also means melting the snow and thawing the lumber. Diffusion of water inside the wood increases rapidly as the temperature rises. Hence the temperature rises through the drying process in order to enhance diffusion.

The next stage is the actual drying. Initially, drying is limited to a speed that ensures that the conditions caused by the removal of lumber from the layers of the stack do not exceed limits beyond which the lumber would be deformed in some way. In this case, the limit is a characteristic of the lumber itself. The drying rate is maintained at a specific level until inversion kicks in and the risks diminish. During the process, it is difficult to measure when this point is reached, but it is generally associated with the fibre saturation point value. Thus the first drying phase is completed when mean moisture content is approximately 30 percent.

The second drying phase follows, during which more rigorous conditions can be applied to help the process. The phase ends when the final preset moisture content value is reached.

The third and final drying phase entails balancing and/or conditioning. Balancing may be required in order to reduce the difference in MC among the sawn lumber units. Conditioning may be required to reduce the difference in MC between the interior and surface of the lumber, at the same time easing induced restrictions.

A drying program schedules changes in kiln air conditions with reference to the above phases. It comprises temperature couples (dry bulb and wet bulb) that help to generate an adequate drying rate. These temperatures become the set-points for the regulating system. A change in the setting (or new stage in the program) results from measurement of a variable in the drying process, from an estimate of the mean moisture content of the sawn lumber units, or simply from the time elapsed. The methods used to change air conditions are the main differences among all commercial control systems currently on the market.

We will now describe the local control mechanism that maintains the air conditions set by the drying program. The regulation of air conditions is the other function of the control system.

C2 Regulating Air Conditions

Air flows in a loop inside the kiln. First it passes through the stack, with the temperature and humidity set by the drying program. Next it goes through heat exchangers and fans; then it is humidified by adding steam or dehumidified by mixing with outside air. The systems must accurately offset the heat losses and steam gains occurring as the air passes through the stack. It is the heating and humidification/dehumidification systems that make it possible to apply and stabilize air conditions that are suitable for lumber drying.

We will now describe the main systems for applying air conditions inside the kiln.

Heating System

The multi-functional heating system ensures that the desired temperatures exist in the kiln. It must offset energy losses due to evaporation, increases in lumber temperature, the heating up of the fresh air intake required to adjust the moisture content in the kiln, and energy lost through kiln walls and doors. Its ability to offset energy loss depends on its power and on air speed. Systems that use steam as an energy source are commonly used for industrial kilns, particularly in Quebec.

Humidification/Dehumidification System

The air is humidified by means of steam injection or cold-water spray. In the industry, the cold-water spray is used primarily in kilns such as direct-fired kilns, which cannot intake steam easily, if at all. Two stages of the drying program require air humidification. The first is the rise in temperature: air humidity must be high to minimize lumber drying. The second is conditioning, the last stage in the drying program. Here, too, steam must be added so that the air humidity restores MC at the surface of the lumber and thus reduces the stresses generated by the difference in humidity between the centre and the surface. In addition, some high-humidity programs require steam to be added during specific periods, mainly because of air leakage into the kiln and poor wall insulation.

Note also that the kiln is equipped with an air-dehumidifier system that operates throughout the drying process, mixing the humid air in the kiln with dry, fresher air from outside through vents that are situated along the length of the kiln roof.

Regulating System

A regulating system is a return system that acts on air temperature and humidity on the basis of the difference between the desired temperature or humidity and measured values. In the case of air heating, for example, it opens or shuts a steam tap depending on the differences in steam temperature. The advantage of a regulating system is that the kiln can operate independently of any outside air disturbances and the variability of the product to be dried.

Appendix D
Additional Information on PID Control Loop

Additional Information on PID Control Loop

Two control loops are required to maintain air conditions inside the kiln. The first loop adjusts air temperature by controlling a heating system, and the second regulates air humidity by spraying water or steam (humidification) or by mixing the air inside the kiln with fresh, drier air from outside (dehumidification). In practice, the heating, humidification and ventilation systems perform this function. In short, two control loops adjust air conditions.

PID

Return systems with a PID component are very common in the industry. Kilns with this component can react to changes triggered by outside events such as a door being opened or the temperature suddenly changing. Specifically, a PID regulator corrects temperature errors in the kiln. PID stands for "proportional," "integral" and "derivative," and each of these terms represents a function that operators could carry out manually if they observe a temperature error in the kiln.

The system works as follows. A proportional action is the opening and shutting off of a tap proportionally to the observed discrepancy between the actual temperature in the kiln and the desired temperature. An integral action is a continuous reaction in the event that the observed error persists in spite of the proportional action on the tap. A derivative action is an amplified reaction directed to the tap once the temperature discrepancy occurs, generating a predictive action and offsetting the slow response of some systems to new demands (in our example, a demand for more energy). All three actions combined define how the regulator works.

Industrial kilns are equipped with other control mechanisms, such as start-stop systems. Humidification in kilns can operate under such a system, which is simple, inexpensive and reliable, but not very precise. One way of improving precision is to shorten the start-stop interval. Unfortunately, doing so wears out the equipment prematurely.

Comparator

The comparator (see Figure D-1) is the part of the return system that relates system input to system output. In our case, it compares the measured value of the temperature in the kiln with the set-point temperature determined by the drying program. This makes it possible to control the tap, for example, by working with the temperature value instead of acting on the system by targeting the heating system tap open/shut percentage. The value of the error detected in this way is used by the PID component of the return system.

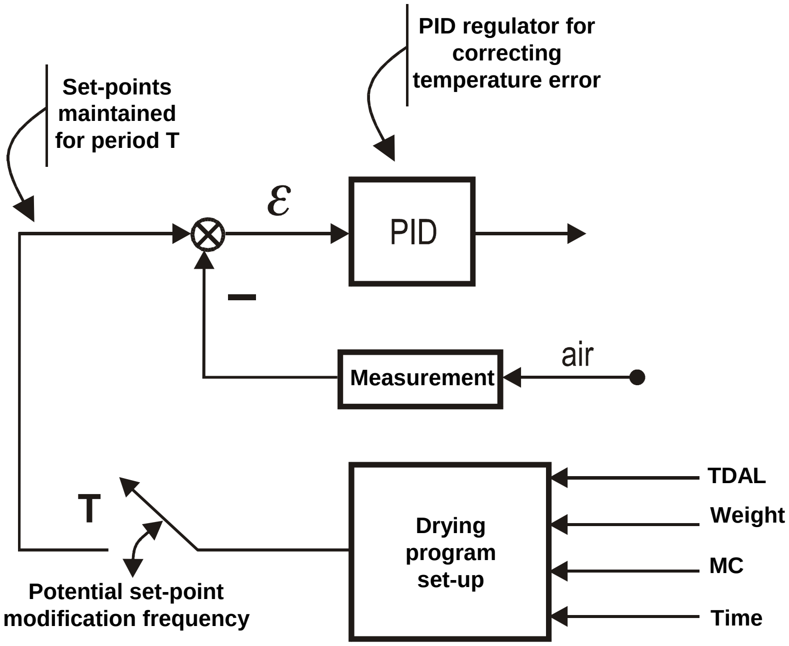


Figure D-1. Details of structure around comparator

To summarize, the error calculated by comparing the measured temperature value and the desired temperature value (set-point) is fed into the PID component, which then adjusts and amplifies the error, thereby activating the heating or dehumidification system. This leads to an adjustment of air conditions, optimizing the drying process.

The error is the variable that operators must monitor constantly. As soon as the error starts increasing, they launch a procedure to identify the causes and try to scale it down. If the error becomes too large, alarms will go off.

Measurement

In today’s computerized, automated systems, measurement is an essential component. Two types of measurement have been established.

In the control loop, measurement is required to maintain air conditions and help the drying process. The target measurements are dry bulb temperature and wet bulb temperature. Sensors measure the dry bulb temperature in the airflow passage. Wet bulb temperature is measured in the same way, generating a temperature reading that provides information on the capacity of the air to evaporate water inside the lumber. The two measurements are then compared with the set-point temperature values of the drying program.

There are other instruments on the market for measuring wet bulb temperature. Measurements of relative humidity, dew point, absolute humidity and equilibrium moisture content (EMC) of lumber all target the same phenomenon—the steam content of the air in the kiln.

The measurements are necessary for the drying program to progress through the different stages. For example, measuring the air temperature differential between stack entry and stack exit generates an estimate for the drying rate. Measuring the total weight of continuous stacking yields data on the progression of the drying process. It is also possible to determine the humidity of sawn lumber control units by inserting probes into them. In fact, any of these measurements can be used to calculate change in lumber moisture content and thereby advance the drying program.

Overall, precise and accurate measurement (in ºC) is important. Drying problems often result from an imprecise and inaccurate reading from a temperature sensor. There are many other reasons, however, not all of which are connected with the sensors. Instruments do not always factor in poor air distribution and cold points in a kiln because they are located in only a few spots.Appendix E
Main Control Systems

Appendix E
Main Control Systems

Main Control Systems

Setting changes in a drying program are generated by measurements that yield estimates of mean moisture content of the lumber units. The methods used to move through the air-condition sequence are one of the main differences among existing control systems. In the following we describe how some of them work.

E1 Time-Based System

Time-based systems are the simplest ones but they are not sensitive to changes in conditions inside the kiln. The operators' role is more important. They must estimate the drying rate and, accordingly, the time the lumber will take to reach a mean moisture content to warrant altering the set-point. Figure E-1 shows the control structure. Note that systems that use time-based sequencing have one less return loop. If lumber conditions upon entering the kiln and climatic conditions remain unchanged, good drying results are possible. As already stated, operators play an important role in this type of system: they are the link between the results achieved and adjustments to the drying programs.

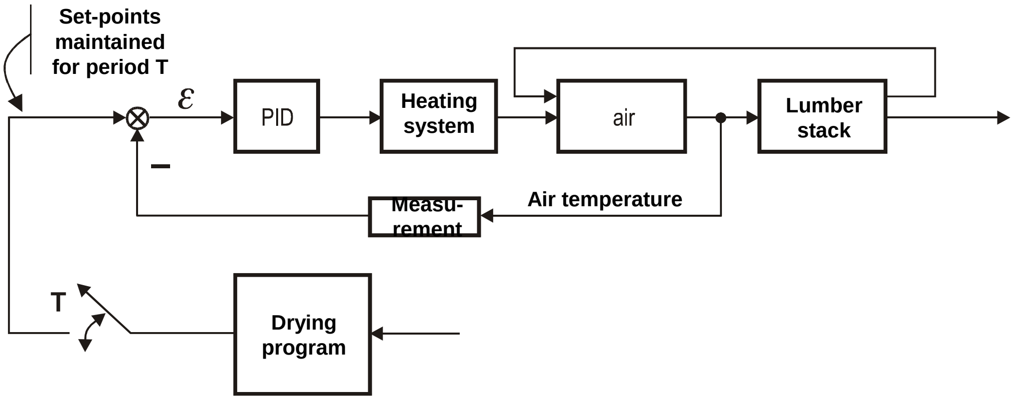


Figure E-1. Control structure of system that uses a time-based drying program

E2 Systems Based on Humidity Detectors

Figure E-2 shows the typical structure of a control system based on measurement of the mean moisture content of lumber. The main difference between it and the preceding structure is the fact that measurement of humidity establishes a link between the drying program and the condition of the lumber. The humidity measurement is compared with threshold values and, once it reaches those values, the drying advances one stage in the sequence, and new set-points are established for dry bulb and wet bulb temperatures.

Moisture content is extrapolated by measuring electrical resistance between two electrodes inserted into the lumber. However, the correlation between humidity and resistance brings in other features of the process and the lumber, such as temperature and density. The precision of the correlation is limited to a range of 5 to 30 percent of moisture content. Manufacturers indicate that this limit may be extended.

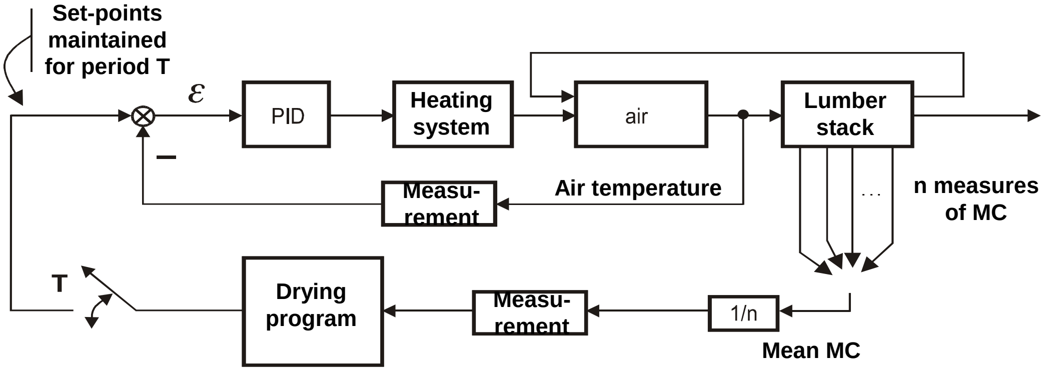


Figure E-2. Control structure of system for program based on lumber moisture content

Load moisture content can be estimated directly, or the moisture gradient of the units can be estimated by inserting a second probe [oo]. In the first case, the operator can run the drying process through successive stages triggered when target humidity levels for lumber are reached; in the second, the operator applies a drying rate that is related to the observed moisture gradient.

[oo] Using the equilibrium moisture content value at the lumber surface, calculated from the air humidity, can replace measurement by the second probe to obtain the lumber moisture gradient.

The interpretation of the MC measurement depends on the number of probes used, the actual MC distribution of the load and representative positioning of probes in the stack. The operator needs to know the confidence interval of the measurement in order to interpret it properly and act effectively on the drying process. Table E-1 shows the number of samples by confidence interval for a sample with 15.5 percent mean MC and 3.0 standard deviation.

Table E-1. Interpreting humidity probe measurement

Mean MC 15.5%	**Confidence Intervals**		
Samples (n)	95%	90%	80%
5	2.63	2.21	1.72
10	1.86	1.56	1.22
12	1.70	1.42	1.11
15	1.52	1.27	1.00
20	1.31	1.10	0.86

Based on this table, we can conclude that, for 12 probes giving 15.5 percent mean MC and 3.0 standard deviation, the probability of the real mean for the full load being between 13.8 percent and 17.2 percent is 95 percent. The operator must be able to interpret the measurement in order to make sound decisions about stopping the drying process.

Although the system receives some feedback from the load, we cannot conclude that it is a return system. The program is preset, even before the start of the process, and it is built on the operator’s experience.

E3 Systems Based on Weight and Load Measurement

Systems based on weight measurement are variants of the preceding system. They have the same structure (see Figure E-2). The scale gives the total weight of part of the load. The moisture content of the load can be calculated from its estimated oven-dry mass. Depending on the degree of precision of the scale, the mean drying rate of the load can also be estimated.

Manufacturers that sell scales install them for a part load. Generally speaking, the weighed part consists of the total load of a cart at one end of the kiln. The observed weight includes the weight of the cart, the spacers and the lumber with its moisture content.

When using this measurement instrument, operators must consider the following facts. The precision of the measurement depends partly on the estimate of the oven-dry mass of the load to be dried. So they must be able to make adjustments to variations in supply. They must also watch for changes in the configuration of the stacks if the number of spacers or the form of the cart is modified.

The other significant fact is the degree of precision of the weigh scale. A scale seems to be precise—for example, to about 0.1 percent (some can be even more precise)—but because only a part load is being measured, it does not take long to reach the limits of the scale's precision capability. Thus, at this level of precision, a load on a cart weighing 18.541 kg (24 × 51 pieces × 0.02108 m^3/piece × 406 kg/ m^3 × 1.77 MC) will be measured at 18.5 kg. If the degree of precision is correlated with the drying rate, the probability of error is 10 percent. The variable effects of air speed may also affect the value obtained. The operator must master these elements in order to interpret the obtained values correctly.

E4 TDAL-Based Systems

Another modern method is the measurement of the TDAL (temperature drop across load). It indirectly generates an estimate of the drying rate and the moisture content of the load—measurements needed to run the kiln. The TDAL triggers changes in the kiln temperature settings. However, the operators must interpret the TDAL measurement correctly in adjusting the drying program.

Figure E-3 presents a block diagram of a kiln using TDAL. Measurement of TDAL entails comparing air temperature measured in the kiln (Te) with the set-point temperature (Tc). The temperature of the air changes constantly as it flows through the stacks because its energy evaporates the water in the lumber. However, TDAL does not yield an absolute value. Interpretation of TDAL depends on the kiln's operating temperature, the space between rows, the speed of the air passing though the stacks, the width of the stacks, etc. In short, TDAL is a function of a number of geometric parameters of the stack and the kiln. Therefore, adjusting drying programs requires precise identification of all the stack and kiln conditions that affect the TDAL value.

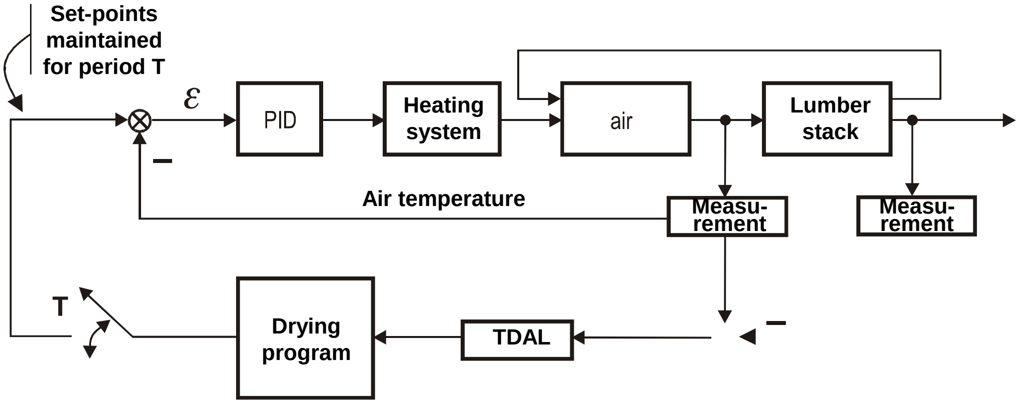


Figure E-3. Control structure for TDAL-based drying program

Once operators fully understand how to interpret TDAL, they can use it to set the drying program when the regulating system allows. It can be used as a factor to determine progression through the drying process or as an indicator of critical humidity conditions in the stack. At the preheating phase, for example, TDAL can be the upper limit for the heating rate. Once it starts dropping (less energy stored in stack), the temperature set-point is raised. Once the set-point is reached, the temperature stops rising.

Next, the drying itself begins. This stage proceeds at a constant drying rate. A constant drying rate equates to a constant TDAL. Let us take an example. To reach a constant rate, once TDAL shows a drop, the dry bulb temperature is raised. By increasing the dry bulb temperature, the operator brings the drying rate back up, and at the same time maintains TDAL. This can be done up to a certain temperature. Beyond that point, the operator waits for another drop in TDAL, indicating the end of the stage.

In the last phase of the drying process, new temperature set-points are established, prompting a brief increase in TDAL and the drying rate. After a while, however, the drying rate goes down steadily. Assuming that the operating conditions remain unchanged, there is an almost linear decrease in TDAL. Projecting the slope, it is possible to predict kiln stop time on the basis of the current drying rate.

The approach is particularly useful because the TDAL value is generally very small, and it is therefore difficult to obtain a real measurement of it. In addition, the TDAL measurement can be imprecise and inaccurate because of all the errors caused by the system. Note also that, in order to set the drying programs correctly, isolate external effects on the TDAL value, and thus lower the reject rate and drying time while using a TDAL-based system, operators need a clear understanding of what TDAL entails.

TDAL is a control system that brings out a relationship between the drying rate and the drying program. However, as in other systems, the target values are preset, so the operator must understand and monitor the drying process in order to improve it.

E5 Variant on Measurement of Temperature in Kiln Control Loop

There are two control loops in the kiln. Each operates independently in terms of regulation function, but they are in fact connected by the events and factors governing air behaviour. Figure E-4 shows the detailed structure of the two loops.

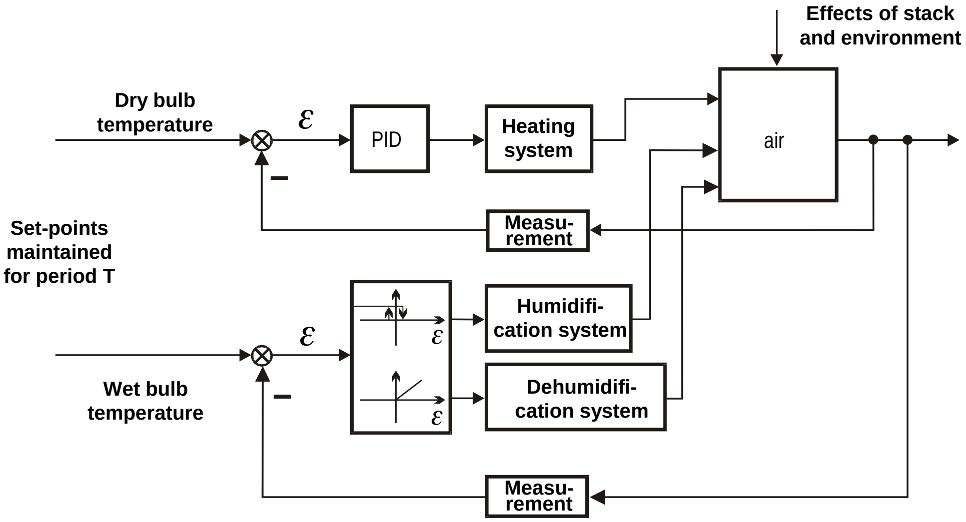


Figure E-4. Detailed structure of kiln regulating system

Figure shows a start/stop component for the operations of the loop regulating humidification and a proportional component for dehumidification. They were chosen strictly for purposes of illustration.

The control loops also influence each other. Let us suppose that the system detects an error in the dry bulb temperature. If the error occurred because the dry bulb temperature is below the set-point, the system will heat up the air. The psychrometric chart shows that when air is heated, it dries out. As a result, another error will be detected on the air humidity control loop. This loop will activate to correct the second error by humidifying the air. On the other hand, humidifying the air causes the dry bulb temperature to rise, resulting in yet another error. This explains why regulating systems have logical sequences giving priority to one of the systems according to the operating stage concerned. Table E-2 summarizes the effect of corrections on temperatures observed in kilns.

Table E-2. Summary of effects of heating and humidification systems on temperatures

	Heating	**Steam humidification**	**Dehumidification**
Dry bulb temperature	+	+	–
Wet bulb temperature	–	+	–

The location of instruments for measuring dry bulb temperature also affects control loop operations. A measurement can be taken as the stack enters the kiln or as it exits. Taking it upon entry ensures that a maximum temperature inside the kiln will be used. In addition, response time is faster because the temperature is adjusted by the heating coils near the measurement point.

Taking the measurement at the exit point ensures a minimum temperature. This is because the stack influences the temperature measurement. If the system has been stabilized after running for a certain period of time, the entry-point temperature will exceed the exit-point temperature by a value proportional to the drying rate. If the direction of the airflow in the kiln changes or if there is a significant variation in temperature, the inertia of the stack will affect temperature. The stack can then supply the air with heat, with the result that the system recognizes that there is no need to supply heat to the kiln, and the temperature at the entry point will therefore start to drop. Operators must have a clear understanding of these facts in order to set drying programs adequately.

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CETC-Varennes 2003-047 (TR) 171-DRYCON

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