DEVELOPING AN EVALUATION PROGRAM FOR LUMBER DRYING OPERATIONS IN BOLIVIA

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Developing an Evaluation Program for Lumber Drying Operations in Bolivia

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(ABSTRACT)

The Bolivian forest products industry has experienced substantial growth during the last ten years. Exports of value-added products have largely replaced logs and green lumber, and raw materials for wood products have shifted to lesser used species. Important investment has taken place in lumber drying capacity, which unfortunately was not always accompanied by sound drying practices. Several non-governmental organizations, with U.S. financial aid, are currently supporting the industry with technical assistance. This project assists these efforts by assembling much needed information regarding lumber drying, and providing tools for performance measurement of drying practices.

A survey was conducted among Bolivian companies to determine lumber drying capacity, technology and practices. Results showed a total drying capacity of 6,104,250 board feet in 167 kilns. Technology and practices used are highly variable. Thirty six percent of kilns are home-made, and 59% are of European commercial brands. Upon completion of the survey, a set of analytical tools was developed and tested in six Bolivian firms. These tools were designed to systematically evaluate lumber drying operations and formulate actions for improvement.

Equilibrium moisture content (EMC) during storage, manufacturing and shipping was monitored in plants located in three Bolivian cities and inside containerized shipments of wood products. Findings showed differences between EMC and lumber moisture content from -1% to 7%. Differences between EMC inside dry-lumber storage and processing facilities varied between 0% and 3.6% and were greatly influenced by facility configuration. Climate during shipment of wood products largely depended on packaging materials and methods, which attenuate sharp changes in ambient conditions. Monthly values for outdoor EMC for the main cities of Bolivia were calculated based on historic weather data and are reported.

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CHAPTER 1 PROJECT DESCRIPTION

INTRODUCTION

Bolivia is located in the heart of South America, sharing the Amazonian rainforests with Brazil. Approximately half of its territory (53 millions hectares) is covered with forest, which represent about the sixth largest tropical forest in the world.

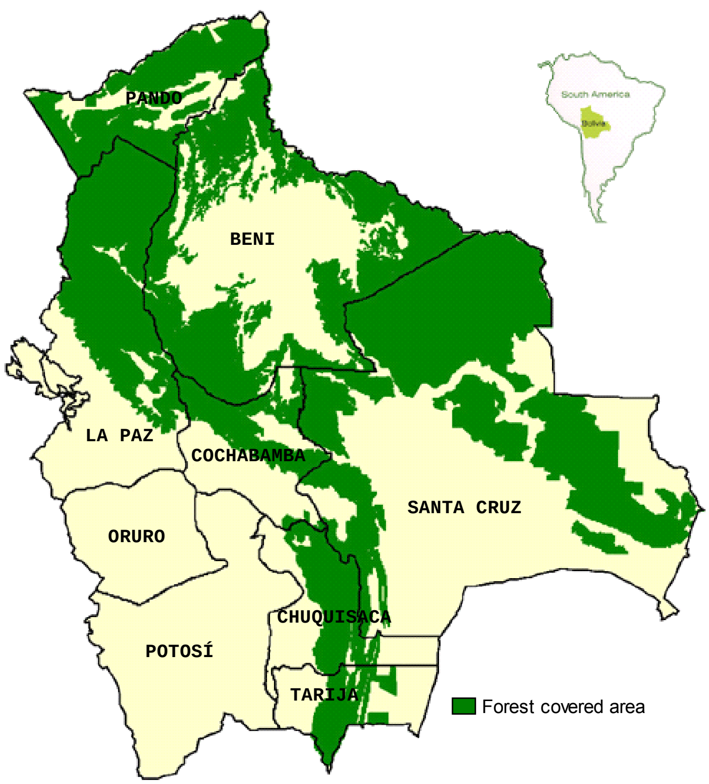

Figure 1-1. Bolivia forestry map (CADEFOR, 2002).

The Forest Products Industry in Bolivia represents 3% of the Gross Domestic Product and employed 90,000 direct jobs in 2002 (Amazonian Center for Forestry Development, 2002). Forest products exports accounted for 6.7 % of total Bolivian exports in 2004 (Ministry for Economic Development, 2005). It is estimated that there is a potential for supplying 18% of global demand of tropical timber in a sustainable manner (CADEFOR, 2002).

Traditionally, three species made up the majority of harvested timber: Mahogany (*Swietenia macrophylla*), Spanish Cedar (*Cedrela odorata*) and Roble or South-American Oak (*Amburana cearensis*), which accounted for 91% of total cut in 1992 (Barany et al., 2003). In 1996 the Bolivian government approved a new forestry law, aiming at the sustainable utilization of forests and stopping the extremely selective harvesting. A government agency was created to enforce the new law, as well as non-governmental organizations with international assistance to support the industry and indigenous communities in sustainable management of the vast forest resources. As a result of these policies, there has been a shift from traditional woods to alternative species, and Bolivia has become the leader in certification of tropical forests, with 1.9 million ha (FSC, May 2005). Figure 1-2 shows the increase in certified forest area and exports of certified wood products.

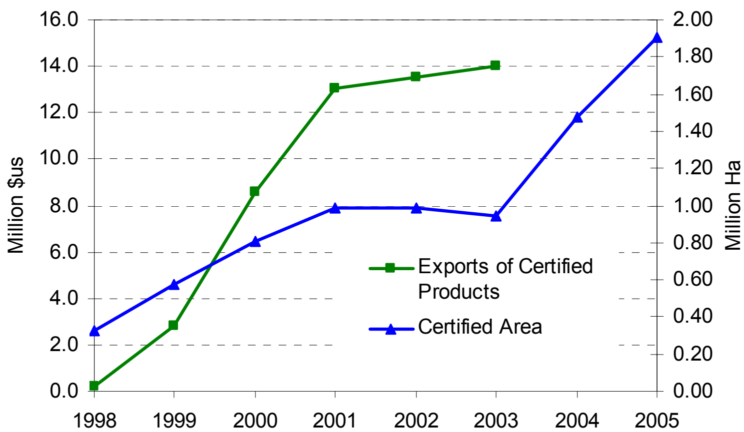

Figure 1-2. Bolivian certified forest area and exports (FSC, 2006 and BOLFOR, 2006)

A traditional exporter of unprocessed raw materials, Bolivia started to boost the manufacturing of products with higher value added after 1996. While sawn lumber is still a significant portion of the forest products exports, it has steadily reduced its participation in total wood products exports (Figure 1.3). Exports of green sawn lumber were partially displaced by exports of products like furniture, millwork and crafts. Logs and sawn lumber accounted for 68% of total forest products exports in 1993. Compare with 24% in 2003. (National Institute of Statistics, 2006).

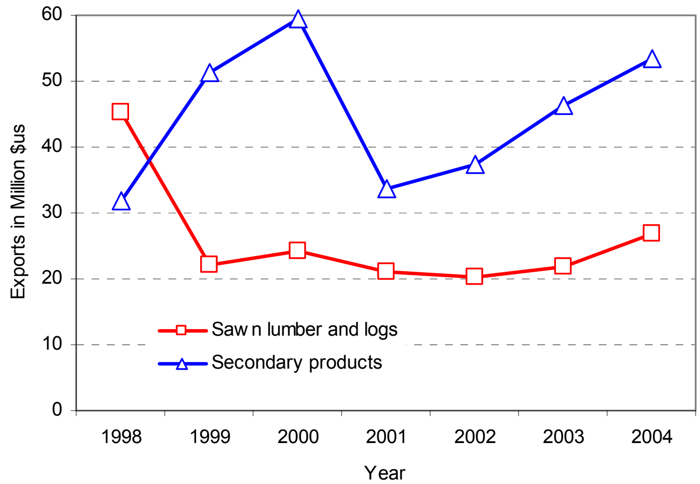

Figure 1-3. Exports of Bolivian forest products for 1998-2004 (Bolivian Forestry Chamber, 2006).

As a result, there has been substantial capital investment by the forest products industry in Bolivia in the past several years; in particular resulting in increased lumber drying capacity. However, there is still a lack of standardization concerning the knowledge and practices of the drying process. Drying methods have been found to be generally inadequate, resulting in poor drying techniques and inefficient use of kilns (Lamb and Araman, 2002; Bond, 2003 and Kabir, 2004). The increasing utilization of lesser used species represents another challenge, since little or no information is available on drying properties of these woods (Barany et al., 2003).

In Bolivia, CADEFOR, a non-profit organization, with technical assistance from Virginia Tech and the U.S. Forest Service, has taken important steps in providing the industry with technical assistance in the form of training in lumber drying, and with development of drying schedules for native species. The present project is intended to assist these efforts and provide the industry with information and tools that can help in the identification of improvement opportunities. Although the technical literature on specific aspects of the drying process apply universally, a comprehensive improvement program for the Bolivian industry must take into consideration the particular characteristics of the country, the state of the drying technology, the resources available, and the skills of the people in charge.

OBJECTIVES

The main goal of the project is to evaluate lumber drying practices in Bolivia, identify opportunities for improvement and provide tools and recommendations for its development.

The specific objectives are:

1) Survey the wood products industry in Bolivia to determine current kiln drying technology, capacity and methods used.

2) Develop and test an evaluation program as an analytical tool for improvement of drying operations.

3) Evaluate the moisture content gain/loss during the processing of lumber and shipping of final products.

RATIONALE AND SIGNIFICANCE

Any project aimed at developing a wood products industry should be based on reliable information about its current status. Unfortunately, this information is almost nonexistent in regards to lumber drying in Bolivia.

No concerted effort has been made to develop proper drying practices and as a result each company has its own methods –frequently not optimal - and knowledge is not shared. An example of this is the fact that companies with comparable technology, product and species use greatly different drying schedules.

Manufacturing facilities are located in regions with marked differences in climate conditions and this is not usually taken into account when making decisions about final moisture content, storage facilities and packaging. This is no surprise since there is no data regarding equilibrium moisture content during these phases of the manufacturing process, and the importance of these factors is in general poorly understood by the people involved.

It is the purpose of this project to play a part in the improvement of lumber drying in Bolivia by providing the industry and its supporting institutions with:

- Information about lumber drying capacity, technology and practices. This information can be used to assess constraints in the wood products industry and design improvement strategies; channeling international aid more efficiently.
- Tools for the evaluation of drying operations' performance. Ideally, this tool could be used by institutions, companies or consultants to systematically evaluate lumber drying operations and formulate specific actions for improvement.
- Information regarding equilibrium moisture content in post-drying stages of the manufacturing process. In order to be effective, decisions regarding target moisture content, storage conditions and packaging of products for shipping must take into account the prevailing climate conditions during these stages.

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CHAPTER 2 SURVEY OF LUMBER DRYING OPERATIONS

ABSTRACT

A survey was conducted in the wood products industry in Bolivia to collect information about lumber drying capacity and technology used. Thirty one companies were surveyed with an adjusted response rate of 81%, and represented 90% of the estimated total drying capacity. Results show an estimated total drying capacity of 6.1 million board feet for 167 kilns. Drying capacity was concentrated in a small number of companies and in the eastern region of the country. Based on the survey results, a greater impact could be expected if improvement efforts were focused on the few big companies and three regions having the majority of drying capacity.

Locally-made kilns made up a significant proportion in the total drying capacity, thus making necessary training in kiln design and inspection methods. Among commercial brands, Europeans ones were the most popular. The age of individual kilns show that the industry has been heavily investing in drying capacity during the last decade, with 88% of kilns being 10 years-old or less. Therefore, many kilns are reaching the age where significant maintenance will be needed.

Mara Macho, Roble and Yesquero made up almost 60% of volume of lumber dried in 2004-05; therefore, kiln schedule development should start with these species. All the companies used moisture content-based schedules and most of these schedules were developed by the companies themselves. The preference for a control method was equally divided between electric probes and kiln samples, but electric probes prevail among commercial kilns, making necessary training in the correct use of this control technique. Most incoming lumber to the kilns is green, 88% of companies receiving material at 70% moisture content or more, consequently schedule development and educational programs should focus on drying green material rather than air-dried or pre-dried lumber.

INTRODUCTION

The Bolivian forest products industry has experienced great changes during the last ten years. Probably the most important is the new forestry law, passed by the government in 1996, it was aimed at promoting proper forest management and sustainable utilization of forests' resources. The law also allowed the participation of the communities in the production and benefits of these resources (Forestry Superintendence, 1996). The new law provided a framework for the sustainable management of forests and reduced extreme selective harvesting. As a result, forest certification was promoted as a management tool. Bolivia now has the largest area of certified tropical forest in the world. Also, communities have turned into important potential participants in the production of wood products and raw materials have shifted from traditional species to lesser used species. After an initially difficult transition period of decreased production and employment, exports of value-added products have grown substantially. This growth has resulted in the wood products industry having invested heavily in manufacturing capacity during the last decade, including lumber drying capacity. Quantifying this growth in capacity would be difficult, since no information on this matter exists, and it is believed that growth in secondary products exports has occurred at the expense of primary ones, such as logs and green lumber.

All the investment in manufacturing capacity – and particularly in drying capacity – was made without any standards. As a result, all aspects of lumber drying are inconsistent throughout the industry, from technology to scale of operations. More importantly, drying practices were also developed without any coordination, and almost every company has its own drying methods. This was confirmed by several visits of Virginia Tech experts in the context of a development project (Lamb and Araman, 2002; Bond, 2003 and Kabir, 2004).

Efforts are being made by non-government agencies, like BOLFOR, CADEFOR and BCCN (Bolivia Forestal, Amazonic Center for Forestry Development and Competitive Bolivia in Trading and Business, respectively) to provide support for the development of the secondary manufacturing industry, in the form of consulting services in several areas including lumber drying.

In order to be effective, the improvement of lumber drying practices should take into account the peculiarities of the Bolivian industry, particularly the state of lumber drying. Therefore, the first part of the project was proposed: conducting a survey with the objective of assessing lumber drying capacity and technology in Bolivia.

Although a previous assessment of drying capacity exists (CADEFOR, 2002), it was carried out informally and lacked specific information, like state of technology, knowledge of lumber drying and current practices which is necessary for determining educational and technological improvement needs. Since one objective of this thesis was to develop an improvement tool for Bolivian lumber drying operations, the aforementioned information was an essential input. Specifically, the survey was used to collect information about:

- Number, origin, age and capacity of kilns in use
- Volumes and species currently dried
- Drying control methods
- Maximum operating temperatures
- Moisture content of incoming lumber
- Energy source

Apart from providing a complete picture of the state of lumber drying in Bolivia, it is believed that the conclusions of the survey and further visits to the industry will also be helpful in:

- Designing training programs for kiln operators.
- Assessing capacity constraints in the wood products industry in Bolivia.
- Identifying opportunities for improvement in the industry, channeling the international aid more efficiently.

LITERATURE REVIEW

Very limited information exists regarding lumber drying in Bolivia. The Forestry Superintendence is a government agency equivalent to the U.S. Forest Service, but apart from enforcing forestry law, they deal very little with manufacturing operations. Non-government agencies provide consulting services in a wide range of activities, from forest certification to business management in the forest products industry, and have created several publications regarding good business and manufacturing practices, but none about drying practices in Bolivia.

Based on visits made to Bolivian companies in three cities, Lamb and Araman (2002), Bond (2003) and Kabir (2004) identified the following characteristics of lumber drying in Bolivia:

- Material is usually green-off-the-saw, 2-inch thick. It is common practice to dry mixed loads, (i.e. different thicknesses and species), all these contributing to a long drying time and low throughput.
- Technology varies widely, with a significant number of homemade kilns. Among the commercial kilns in operation, the majority is of European origin.
- Knowledge of operators and managers varies broadly, and usually learn by doing, without a clear understanding of the drying process.
- Drying is done very conservatively and no standard schedules are in use.
- Air drying, kiln loading and stacking practices need improvement.

CADEFOR carried out a lumber drying capacity assessment in 2002, to determine drying capacity in the Bolivian industry; origin and type of kilns were also assessed. They did not directly survey the companies but collected information informally from consultants who have close contact with the industry. The results identified 44 drying operations and 155 dryers, with approximate 5,253,700 board feet of total drying capacity. Results about origin and geographical distribution are shown in Figure 2-1.

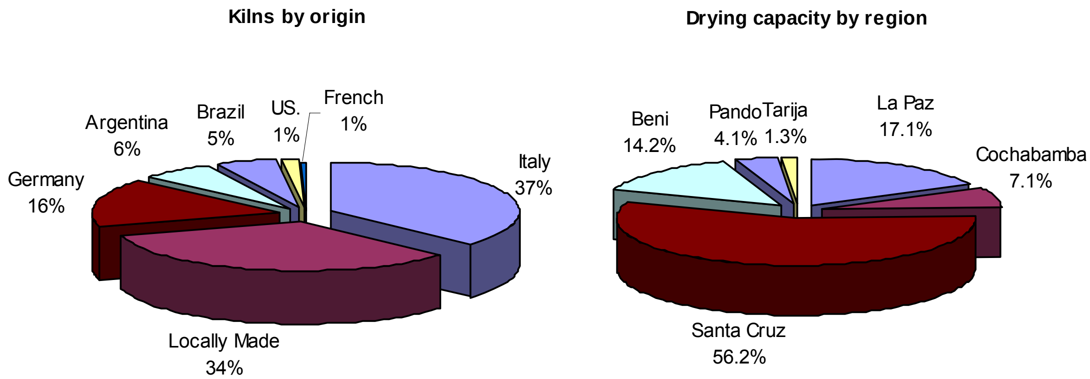

Figure 2-1. Lumber drying capacity assessment by CADEFOR (2002).

A great deal of information can be found on lumber drying capacity and technology in North America. A national survey of lumber drying was carried out in the United States by the US Forest Service carried in 1992-93 (Rice et al., 1994). The methodology used was a two-page survey conducted by phone, covering general information about the company, species, proportion of air-dried material, type of kilns, type of schedules and species and volumes dried. Similar surveys were done in Alaska (Nicholls and Kilborn, 2001) and West Virginia (Armstrong, 1984). Surveys about more specific aspects of lumber drying were also completed: a mailed survey was carried out in 799 U.S. and Canadian companies (Little and Moschler, 1992) to investigate the extent of corrosion problems in different types of kilns and the use of protective coatings. 24 firms in Tennessee were surveyed in year 2001 (Bond and Hamner, 2003) to find out stacking methods, its impact on yield and information regarding species dried and kiln capacity. The occurrence of crook after drying in the furniture and cabinet industry of West Virginia, Virginia and North Carolina was investigated in 2003 by surveying 14 manufacturing companies (Wiedenbeck et al., 2003).

Information regarding lumber drying operations in Bolivia was almost nonexistent and no systematic effort was made to collect data regarding capacity, technology and practices. The only assessment of lumber drying capacity was made informally and data is out of date. Since any project to develop lumber drying must take into account the particularities of the industry, it is believed that a survey to gather this information was needed.

METHODOLOGY

Since the target population of the survey was all Bolivian companies owning at least one kiln, the first step was to develop a list of companies meeting this requirement. Such a list did not exist. To accomplish this, the names of companies involved in the wood products industry was first collected with the purpose of narrowing it down to only companies with kilns. The methodology used is illustrated in Figure 2-2.

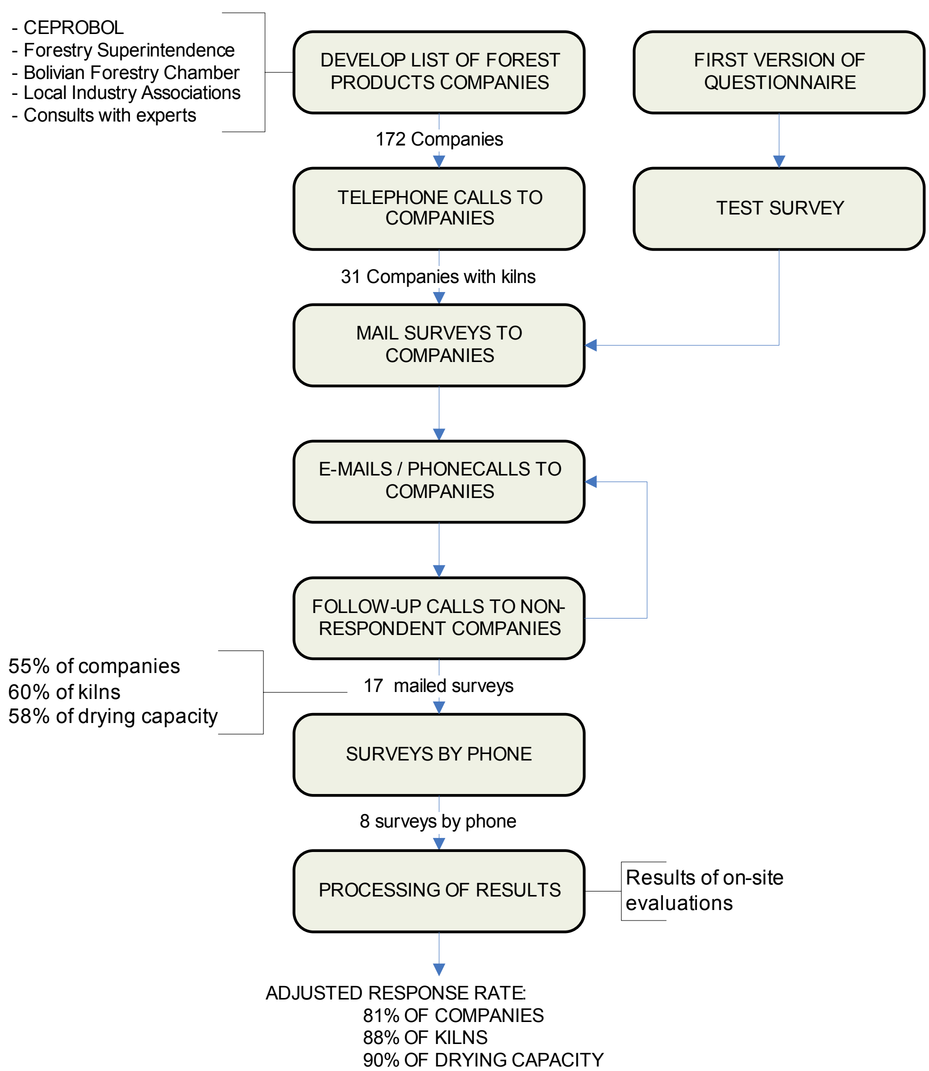

Figure 2-2. Methodology used for surveying Bolivian lumber drying operations.

The first list was prepared consulting the following sources:

- Bolivian Center for Promotion (CEPROBOL), a government agency for the promotion of exports. They provide a directory of exporting companies by product category, which in turn was developed with the participation of chambers of exports in all the cities. Since Bolivian law requires the companies to report all exports to these local chambers, it is believed that the list provide an accurate representation of companies involved in exports of wood products.
- National Chamber of Industry (Cámara Nacional de Industria). This entity comprises all local chambers of industry and provides a list of affiliated industries by product category. All medium to big-sized companies are affiliated to this institution.
- Bolivian Institute of Statistics (Instituto Boliviano de Estadística). This is the Bolivian government agency in charge of all national statistics. A directory is available at their website where companies can be listed by selected criteria.

The result was a list of 172 companies related to either the manufacturing or commercialization of wood products. The initial list had to be reduced to consider only companies having lumber drying operations; this was done by conducting phone calls to all of them, asking whether they owned at least one dry kiln. After the phone calls, the list was narrowed down to 40 companies running lumber drying operations. Further reductions included eliminating duplicated data, mainly companies which operate under two different names, reducing the total number to 31, which constituted the target population of the survey.

With the objectives of the survey in mind, a first version of the questionnaire was designed and tested at one Bolivian company. Based on the feedback provided, minor format changes were made and a final version was prepared (see Appendix A).

Once the companies of interest were identified, questionnaires were mailed to them, with a cover letter from CADEFOR - the Bolivian partner for this project – explaining the purpose of the survey, the institutions involved and instructions for filling out and submitting the survey. Nine companies returned surveys within two weeks of the mailing, and then 22 follow-up calls were made and e-mails sent to non-respondents. Eight more companies returned the survey after these follow-up contacts, making up 17 respondents and representing 55% of the target population by number of companies.

Since it was very important for the purpose of the survey to have at least capacity information from all the companies, it was decided to conduct surveys by phone to the remaining 14 non-respondents, and as a result 8 answered all the questions and 6 only answered basic questions about the number and capacity of kilns. These last six companies are not considered in the adjusted response rate. The resulting adjusted response rate is then calculated as 81%, by number of kilns and representing 90% of the total drying capacity.

RESULTS AND DISCUSSION

The results of the survey were complemented with information gathered during on-site evaluations at six drying operations in Bolivia. They will be discussed in Chapter 3. The following sections show the results and analysis of the survey.

Total Drying Capacity

It is important to note that drying capacity in companies not currently working was included in the calculated total drying capacity when it was considered that their facilities are in operating condition.

According to the results of the survey, the total installed lumber drying capacity is 6,104,250 b.f. (2-inch lumber basis) in 167 kilns (Table 2-1). The only available data to compare these numbers with is the assessment made by CADEFOR in 2002, where a total drying capacity of 5,253,700 b.f. in 155 kilns was estimated. The difference can be explained by investment in new kilns during the last three years (32.9% were found to have kilns with 5 or less years in operation) and/or the incompleteness of the previous survey.

Table 2-1. Lumber drying capacity and number of kilns by department.

Department	Number of kilns	Capacity (board feet)
Santa Cruz	98	3,791,250
La Paz	26	782,000
Beni	14	610,000
Cochabamba	15	508,000
Pando	9	345,000
Tarija	5	68,000
TOTAL	167	6,104,250

It was also found that lumber drying capacity is rather concentrated, with 33% of the companies owning the 70% of the total capacity.

Drying Capacity by Geographic Zone

Six out of nine departments (main political divisions) were identified as having lumber drying operations, and capacity distribution among them is shown in Figure 2-3. Santa Cruz has by far the largest drying capacity, with 62.1% of the total, followed by La Paz (12.8%) and Beni (10.0%).

Figure 2-3. Lumber drying capacity by department.

The large proportion of Santa Cruz to total drying capacity can be understood by looking at volumes of extracted timber volumes as shown in Figure 2-4, where Santa Cruz has 56.9% share in 2005. Also the majority of secondary processing plants are located close to main cities, where qualified labor, services and the required infrastructure exists; thus, a great part of timber extracted in Beni and Pando is shipped to Santa Cruz, La Paz and Cochabamba to be dried and processed (see map in Figure 1-1).

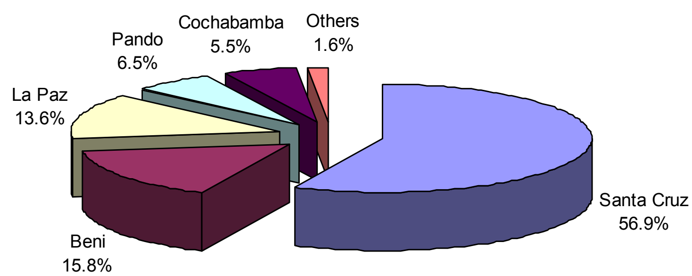

Figure 2-4. Extracted volume of wood by department in 2005 (Forestry Superintendence, 2006).

Species and Volumes Dried

The survey asked the companies the volume of each species regularly dried per month or year. The estimated total volumes and relative proportions are shown in Figure 2-5.

Species	Volume dried* b.f./year
Mara Macho	14,515,329
Roble	9,833,475
Yesquero Negro	5,332,428
Almendrillo	3,797,343
Paquio	2,692,100
Ochoo	2,398,040
Cambara	2,029,429
Bibosi	1,639,765
Tajibo	1,436,541
Quina	1,263,216
Others	4,980,078
TOTAL	49,917,743

* Adjusted for response rate

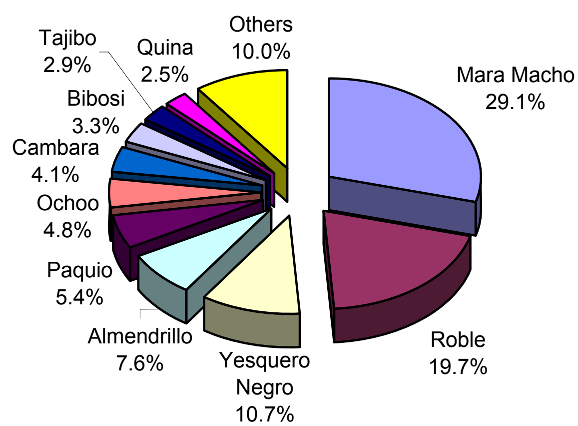

Figure 2-5. Volume of species dried.

The previous figures can be associated to the main products exported and species commonly used for each product category:

- Doors and millwork (51% value of 2005 wood products exports, according to CEPROBOL website). Mara macho (*Cedrelinga catenaeformis*) is the most common species used for doors and millwork, followed by Yesquero Negro (*Cariniana estrellensis*), Bibosi (*Ficus spp.*) and Ochoó (*Hura crepitans*).
- Furniture and furniture parts (36%). Regarding outdoor furniture, the species chiefly used are Roble (*Amburana cearensis*), Paquió (*Hymenaea courbaril*), Almedrillo (*Dipterax odorata*) and Tajibo (*Tabebuia impetiginosa*); whereas interior furniture is usually made of Cedro (*Cedrela odorata*), Mahogany (*Swietenia macrophylla*), Yesquero Negro and Roble.
- Flooring (12%). In general, species used for garden furniture are also used for flooring, and others like Palo María (*Calophyllum brasiliense*), Cuta (*Phyllostylon rhamnoides*).

Comparing what the industry is currently using and what is available in the forests helps to show whether timber is being used mostly for added-value goods or as exports of primary products. Figure 2-6 shows the estimated stock of main Bolivian species. Six of the ten most dried species - 60% of total volume dried – can also be found among the ten most abundant woods, which represents 45% of the total estimated stock. This is a positive indication of the shift in raw materials since the approval of the new Forestry Law in 1996, when the Bolivian government implemented several changes aimed at promoting the sustainable utilization of forests, by stopping the extremely selective harvesting, increasing the manufacturing of value-added products and encouraging certification of forests and manufacturing operations. In contrast, during 1992, 91% of total cut was composed of Mahogany, Spanish Cedar and Roble (Barany et al., 2003).

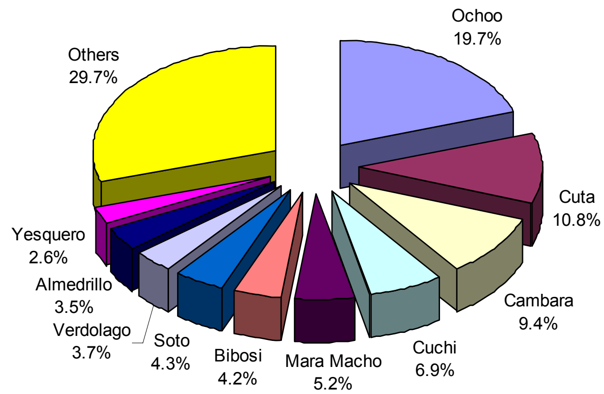

Figure 2-6. Most abundant species (estimated stock in permanent production areas, BOLFOR, 2006).

Origin and Brand of Kilns

The suspicion that a significant proportion of kilns were built in Bolivia was confirmed by the results of the survey (Figure 2-7): 36% of the kilns - by number of kilns - were found to be locally-made; Italian kilns have a 36% share of total kilns due to an aggressive sales effort in Bolivia. German kilns are also popular, with a 23% share.

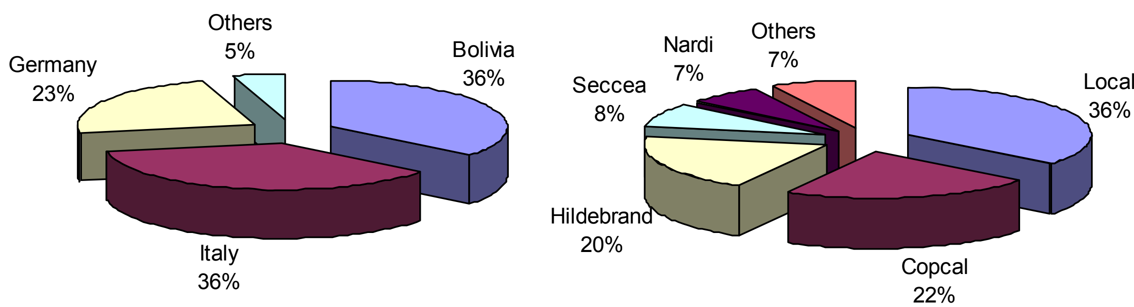

Figure 2-7. Origin and brand of kilns.

Regarding kilns made in Bolivia, some are built by local shops, which usually have some experience and sell dryers as turn-key projects; others are home-made, or built by the companies themselves with materials and parts bought in local stores and subcontracting the fabrication of some components. Home-made kilns are usually operated manually and made of brick and concrete, or even wood-base components. In all cases, electronic components are always imported. Regarding commercial brands, after locally made kilns (36% of total kilns), Copcal is the most popular (22%), followed by Hildenbrandt (20%). Figure 2-8 shows some examples of kilns.

Figure 2-8. Examples of kiln technology: (1) wooden kiln, (2) kiln in construction, (3) 27-year-old line-shaft Irvington Moore kiln and, (4) automatic-controlled Mahil kilns.

Age Issues

Most kilns are relatively new: almost 90% of them are ten or less years old (see Figure 2-9), meaning that the Bolivian forest products industry has been heavily investing in drying capacity to meet its demand for value-added products, mostly to the United States, where about 50% of total forest products exports are sent, according to the Forestry Chamber of Bolivia (Bolivia signed the Andean Trade Promotion and Drug Eradication Act with U.S. in 2002 that eliminate tariffs on certain goods, wood products among them, in exchange for drugs-law enforcement).

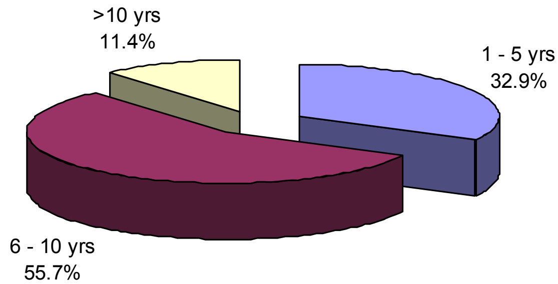

Figure 2-9. Age of kilns.

The growth in exports of primary and secondary-manufacturing products is reflected in Figure 2-10. Since the value-added products are the ones demanding drying capacity – sawn lumber and logs are exported green – the growth in secondary manufacturing products is consistent with the average age of Bolivian kilns.

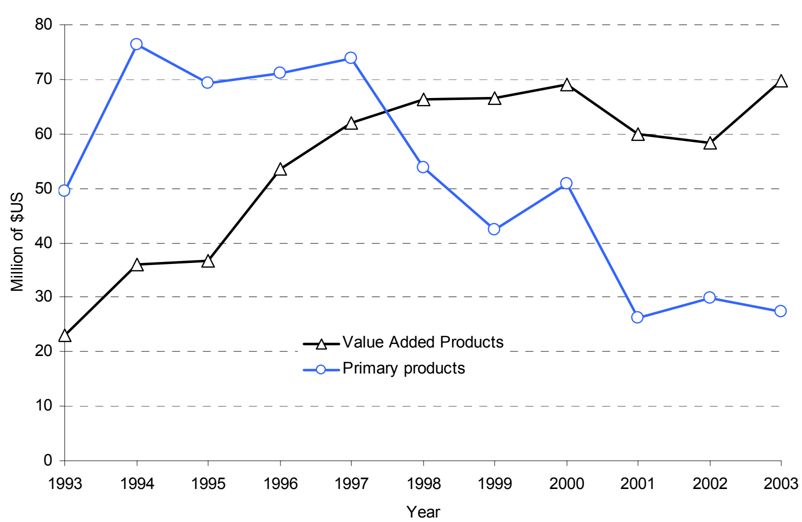

Figure 2-10. Forest products exports by degree of industrialization from 1993 to 2003 (BOLFOR, 2005).

Average Kiln Size

According to the results of the survey, the average capacity per kiln is approximately 36,500 board feet (2 in. basis). Compare this with the average capacity of hardwood kilns in the US: 48,700 to 55,300 board feet in 1-inch basis (Rice et al., 1994). This means about 61,800 to 70,200 b.f. in 2-inch basis (to compare equal units) almost twice the average capacity as Bolivian kilns. However, kiln size is highly variable (Figure 2-11).

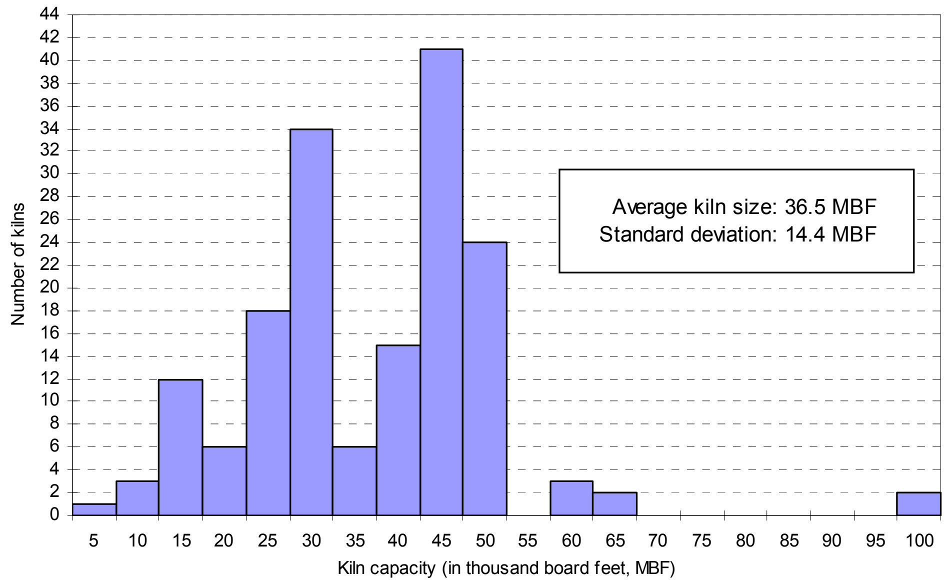

Figure 2-11. Average kiln size distribution.

Possible reasons to explain the preference for relatively small kiln sizes are: 1) being able to respond quickly to a highly variable market and 2) the need to process several species at the same time, and 3) high financial costs for the investment required.

Moisture Content of Incoming Lumber

The majority of companies receive lumber “green-off-the-saw”; this was reflected in the results of the survey: 70% of the companies answered that more than 75% of their incoming lumber to the kiln is “green” (Figure 2-12).

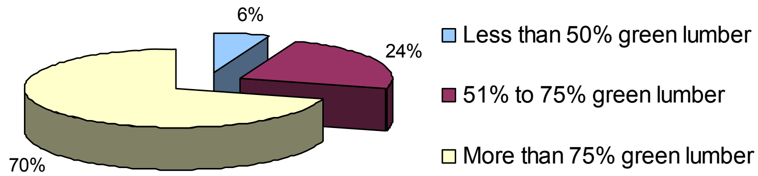

Figure 2-12. Proportion of green lumber coming into the kilns (by number of companies).

Air drying is not a common practice in Bolivia (only one company air-dries some of its lumber in Santa Cruz), and this puts a lot of pressure on kiln drying capacity. Among the reasons for the unpopularity of air-drying in Bolivia are:

- High financial costs of keeping great inventories during long periods of time. Adding to the difficulty, most lumber in Bolivia is sawn to 2 inches. As an example, air-drying 2-in. red oak in the Mid-South in the U.S. takes 215 to 300 days, whereas the time for 1-in. lumber is 55 to 100 days (Forest Products Laboratory, 1999).
- Prevailing weather. In tropical regions 90% relative humidity is common during summer and spring months, and as low as 25% during winter months in La Paz (Wunderground, 2006).
- Market variability. Having significant quantities of lumber in a yard reduces a company's flexibility to react to market changes.
- Many Bolivian species are check-prone, and long exposure to environment causes extensive end and surface checking.

Energy Source

Natural gas is relatively affordable and available for industrial use in the three main cities: La Paz, Cochabamba and Santa Cruz. As was expected, a significant proportion of industries in these three departments use natural gas as energy source for heating dry kilns, as can be seen in Figure 2-13. Wood residues invariably refer to dry scrap wood; there are no wood-dust boilers in Bolivia.

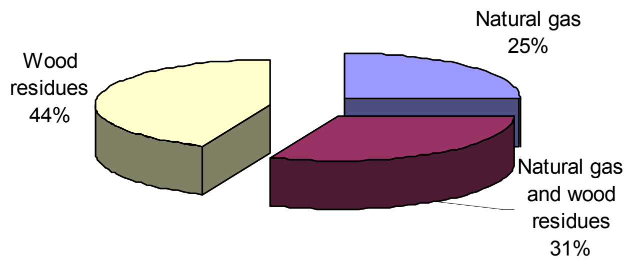

Figure 2-13. Kilns' energy source (by number of kilns).

Figure 2-14 shows the distribution of the different types of fuel by geographic zone. It can be seen that wood residues is mostly used in those regions where natural gas is not easily accessible or not accessible at all.

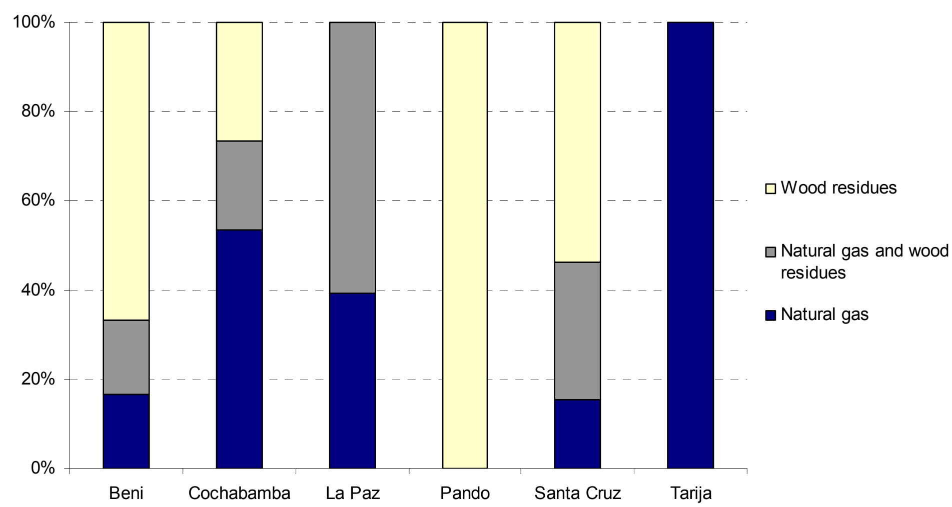

Figure 2-14. Fuels used for drying by geographic zone (by number of kilns).

Drying Process Control

All respondent companies answered that control of the drying process is based on moisture content (M.C.) of wood. The preference for a M.C. measuring technique was equally divided between kiln samples and electric probes and usually depends on whether the kiln is locally made or imported; 100% of locally made and 29% of imported kilns are controlled with sample boards and 71% of imported kilns are controlled with probes (Figure 2-15).

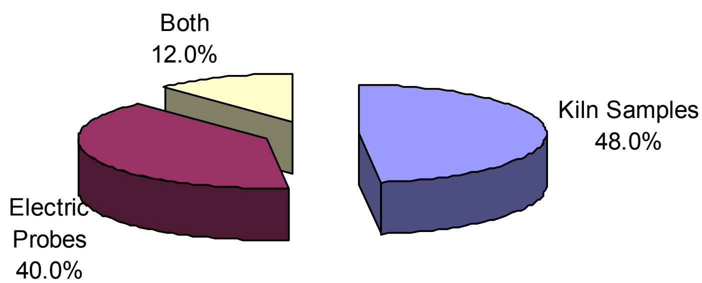

Figure 2-15. Method used for moisture content measurement (by number of companies).

Maximum Operating Temperature

The majority of kilns (65%) have a maximum operating temperature between 71 an 80°C (160 to 175°F) which is not too different from U.S. kilns (69% of US kilns operate at maximum temperatures between 160-180°F, (Rice et al., 1994). However, it is important to consider that maximum operating temperature represents the highest temperature that can be reached by a specific kiln, and not necessarily the temperature at which it is normally run. While temperatures in kiln schedules for hardwoods reach 160 to 180°F in the U.S., Bolivian operators rarely dry lumber at more than 150°F (65°C). Results are shown in Figure 2-16.

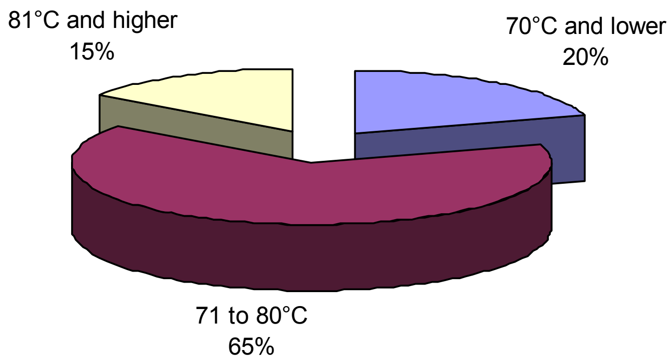

Figure 2-16. Maximum operating temperature (by number of kilns).

Source of Drying Schedules

Unfortunately, little has been done in Bolivia to develop standard drying schedules for the most common species. Although drying schedules for tropical species can be found in the literature, these are usually approximations based on specific gravity or similarity with others species, and have not been thoroughly tested. This is reflected in the lack of standard schedules in the industry, and companies usually develop their own programs by trial and error. Since there is no knowledge of safe drying rates and maximum initial temperatures for most common species, this may be one of the main reasons for drying too conservatively, at relatively low temperatures and high humidity.

Figure 2-17 shows the results for the question about source of drying schedules. Note that some companies cited more than one source.

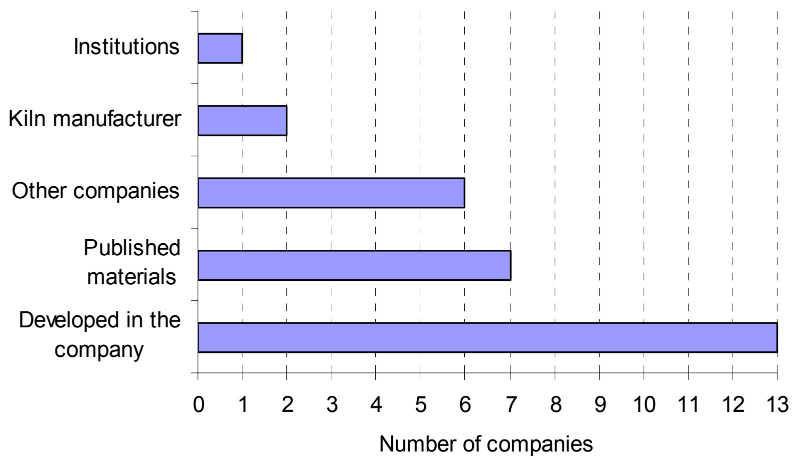

Figure 2-17. Source of drying schedules (by number of companies).

Thickness of Incoming Lumber

It was not possible to determine the exact volumes of lumber thicknesses dried, because the survey did specifically ask for this information. Figure 2-18 shows results for this question. Later visits to the companies indicate, however, a prevalence of 2-inch lumber.

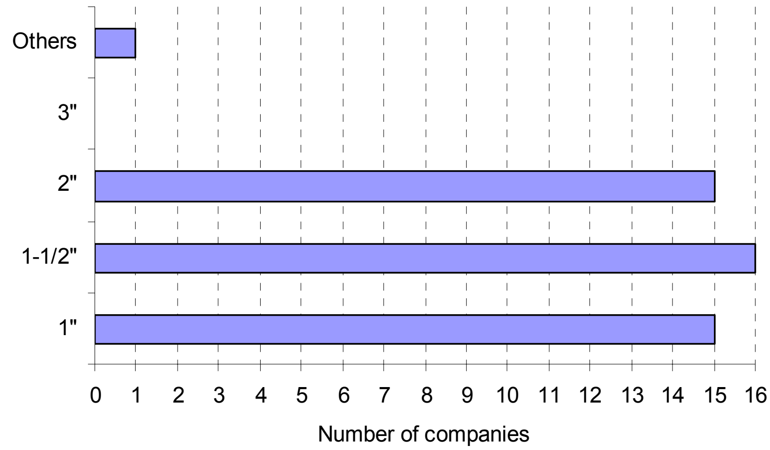

Figure 2-18. Lumber thicknesses (by number of companies).

Type of kilns, equalization and conditioning steps.

A great majority of kilns are steam heated (98%), the remaining 2% consists of steam chambers and a pre-dryer. Also, hundred percent of the companies answered that they perform equalization and conditioning steps for every drying load, although their procedures vary greatly from one company to another, as observed during on-site visits. These differences and the on-site evaluations are discussed in the next section.

CONCLUSIONS

The Bolivian wood products industry was surveyed to determine current lumber drying capacity, technology and methods used. A list of companies was developed and narrowed down to companies owning at least one dry kiln. Thirty one firms were surveyed with an adjusted response rate of 81%. Respondent firms represent 90% of drying capacity.

Based on the results, the estimated total lumber drying capacity is 6,104,250 board feet in 167 kilns. Lumber drying capacity is concentrated in a small number of firms. One-third of the companies own 70% of total capacity. Thus, the best way to positively impact lumber drying technology in Bolivia would be to focus on these few big players. Capacity is also concentrated geographically. Training and kiln improvement methods would make the greatest impact if done in Santa Cruz, La Paz and Beni, which make up 85% of drying capacity.

The two most commonly dried species are Roble (*Amburana cearensis*) and Mara Macho (*Cedreling cateneaformis*) with almost a half of total volume dried. Apart from Roble, all the major species dried are considered alternatives woods, which may be due to the new forestry law in reducing the selective harvesting of forests. Since there are no standard kiln schedules for these species, development and improvement should begin with Mara Macho, Roble and Yesquero, since they make up almost 60% of volume of lumber dried.

Companies chiefly develop their own schedules, but they also resort to published materials and past experience of other companies. There is a marked preference to control the drying process with probes when companies own commercial kilns, so training in proper use of probes would lead to significant improvements in lumber drying in these companies. All firms include equalization and conditioning steps in their drying schedules.

Locally-made kilns constitute 36% of all kilns. Among commercial brands, Italian and German are preferred, making up 59% of total number of chambers. Kilns are relatively new, having 90% ten-years old or less. This indicates that many kilns are reaching the age were significant maintenance will be needed. The average kiln size is rather small, 36,500 board feet but highly variable, almost half of that in the U.S. Some probable reasons for this are variability of the market, need to process mixed-species loads, long drying times and the need to stagger loads to keep steady flow to the processing plants.

Since a large percentage of kilns are home-made, education of proper kiln design and inspection methods would likely improve drying efficiency. Education, improvements and schedule development should also focus on drying green lumber rather than air-dried or pre-dried material, since most of lumber in Bolivia is dried green-off-the-saw.

Some limitations and considerations of the information collected in the survey are listed below:

- Because of the way the questionnaire was designed, the exact volumes of lumber dried of different thicknesses could not be assessed.
- Lumber drying capacity is concentrated in a reduced number of companies; thus, any change in species used or capacity of these firms can have a great impact in the future validity of the data.
- A number of companies not currently operating but with drying facilities in good conditions could be identified. These companies were included in the total drying capacity estimation.

As suggestion for future research, a periodic survey could be conducted to update the data in this survey; allowing to identify trends in species, upgrades or new operations, and shifts in products. This will enable the supporting institutions to provide better services to the industry, consistent with the current trends and market dynamics. Volumes of lumber dried at different thicknesses should be identified to determine where schedule development should begin. To the best knowledge of the author, this is the first survey of its type in Bolivia. Results are believed to provide a fairly complete picture of the state of Bolivian lumber drying capacity, technologies and main practices. This information can be used for assistance planning and – in combination with the results in later sections – in designing improvement strategies for lumber drying operations.

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CHAPTER 3 DEVELOPMENT OF EVALUATION TOOL

ABSTRACT

A set of analytical tools for the evaluation of lumber drying operations was developed and tested, it consists of a comprehensive inspection checklist for assessing performance of the different components of drying, a spreadsheet-based interface to enter data and report results, and ample information regarding proper drying practices.

Six Bolivian companies making up 29% of total lumber drying capacity were chosen to conduct trial evaluations, aiming at representing a wide range of technologies and methods. Results were reported to these companies with recommendations for improvement. Drying practices common to the industry were also analyzed and, where appropriate, better alternatives are suggested.

The result of this effort was a set of analytical tools that can be used by the industry, institutions and consultants to improve lumber drying operations by providing companies with means for performance evaluation and also as an information source on drying practices for the industry in general. These tools will be handed over to CADEFOR, a local non-governmental institution for their promotion and implementation.

INTRODUCTION

Drying to a target moisture content as uniformly and quickly as possible, with minimum waste and quality degrade are probably the most common objectives of any drying operation. Most quality problems in secondary solid wood products are moisture content-related, and drying is frequently the biggest component in the lead time. Thus, it is in the best interest of the industry to develop good drying practices - from kiln maintenance to quality control - to assure the supply of a raw material that meets or exceeds the minimum requirements to be further processed into final products.

Lumber drying in Bolivia presents many challenges. Lack of road infrastructure makes the transportation time from harvest site to the sawmill and from there to the drying facilities considerably long and usually without the appropriate protection, which facilitates the development of defects like stain or checks, depending on the species. Lumber is usually sawn to 2-inch thickness and most species processed have relatively high specific gravity, which contributes to long in-kiln times. Most commercial kilns are of European origin, and because of size of the industry, representatives are not usually located in the country, making the maintenance of complex components a long and difficult process.

Conclusions by Virginia Tech representatives (Lamb and Araman, 2002; Bond, 2003 and Kabir, 2004) and results from the survey conducted in the first part of the project show a lack of standardization both in technologies and practices among Bolivian lumber drying operations. Knowledge of lumber drying principles among Bolivian kiln operators is highly variable as well, and most of them learn by doing.

The challenges of lumber drying operations previously discussed indicate a need for some improvement in the industry. Improvements in drying times and drying quality would lead to a more efficient and competitive industry in Bolivia. The development of an evaluation tool for lumber drying operations would assist in improving drying processes. Ideally, this tool could be used by institutions or companies to systematically evaluate lumber drying operations. The tool should include a checklist to carry out the inspections, a user-friendly interface and supporting information about each area being evaluated so that improvements could be made.

The objective of this part of the project was to develop and test an evaluation tool for assessing drying operations using a systematic approach. The evaluation tool would enable companies to identify weaknesses and suggest actions for improvement.

An evaluation tool was developed using literature and knowledge of drying operations and was tested by conducting trial inspections in Bolivian companies. The visits also allowed the authors to collect additional information about specific drying practices, which is essential when designing improvement strategies, both at institutional and company levels, especially concerning training programs for kiln operators and production managers.

LITERATURE REVIEW

Literature about improvement of drying operations is extensive and most deals with specific technical aspects of drying, like the effect kiln conditions in drying time and quality, drying schedules for certain purposes, the effect of logging practices in drying quality. Books like the USDA's Forest Product Laboratory publications, the "Dry Kiln Operator's Manual" (Simpson, 1991), and "Drying Hardwood Lumber" (Denig et al., 2000), provide complete guidelines for all aspects of the drying process, including physical properties related to drying, stacking, loading, kiln operation and dry lumber storage. The "Manual of the Andean Group for Lumber Drying" (López et al., 1989), is a book about lumber drying written specifically for countries of the Andean Group (comprised by Bolivia, Colombia, Ecuador and Venezuela) and includes similar contents as the Dry Kiln Operator's Manual, plus some considerations about drying costs, kiln construction and drying schedules for most common species in South America. Within the same project, the Andean Group has conducted research regarding air-drying at several locations in he countries comprising the Accord of Cartagena (Cartagena Accord, undated), and published materials with guidelines about proper practices and air-drying times.

The USDA Forest Service has published a series of materials within the IMPROVE project aimed at measuring and improving lumber drying operations. "Quality Drying of Hardwood Lumber" (Boone et al., 1992) includes checklists that can be used to evaluate drying operations. It covers preparation activities, operating practices, process control, kiln conditions and drying degrade. The way these checklists work is by assigning ratings to the different aspects of the drying process in order to identify those areas that need attention. The tool can be used to make an overview of the entire drying operation or to closely check a particular kiln.

Air Drying of Lumber (Forest Products Laboratory, 1999) and Quality Drying in a Hardwood Lumber Pre-dryer (Wengert and Boone, 1993), both publications of the USDA's Forest Service contain guidelines and checklists to assess air-drying and pre-drying operations respectively.

The Dry Kiln Operator’s Manual contains general guidelines about kiln maintenance and inspection and an inspection checklist is also provided, covering kiln structure, control systems, heating and humidifying system and air circulation. The checklist does not use a rating scale and is entirely qualitative.

Currently, most evaluation programs focus on one aspect of the drying process or one piece of equipment; some rank or provide checklists for systematic maintenance. No evaluation program currently provides feedback on the importance of correcting particular problems. Also, many checklists include information that is not practical to collect or relevant to Bolivian drying operations.

No improvement programs in the fashion of the aforementioned materials are designed specifically for Bolivia, mainly due to the lack of standardization in drying practices. The development of such an improvement program would likely be useful in improving drying operations in Bolivia, resulting in more efficient and competitive companies.

METHODOLOGY

A first version of the evaluation checklist was developed, in the same fashion as the one by the Forest Products Laboratory (Boone et al., 1992), but was adapted to drying operations in Bolivia, according to the results of the survey carried out in the first part of the project.

Some of the significant differences with the mentioned tool are listed below:

- Were appropriate, more quantitative measures were included in the inspections.
- Only the aspects applicable to the Bolivian industry were included, and some others were added, like quality control and management of the drying process.
- The evaluation process is made easier with a user-friendly interface, including online help for each question and short theory for each aspect being evaluated.
- A summary of the important indicators and some calculations are automatically calculated and reported.
- A rating system was not included.
- The materials included in the set can be used as educational resources.

It is intended that personnel with only basic knowledge of drying principles would be able to carry out the evaluations, although the participation of a more knowledgeable person is still needed for the recommendations phase.

Figure 3-1 depicts the methodology used for the development of the evaluation tool.

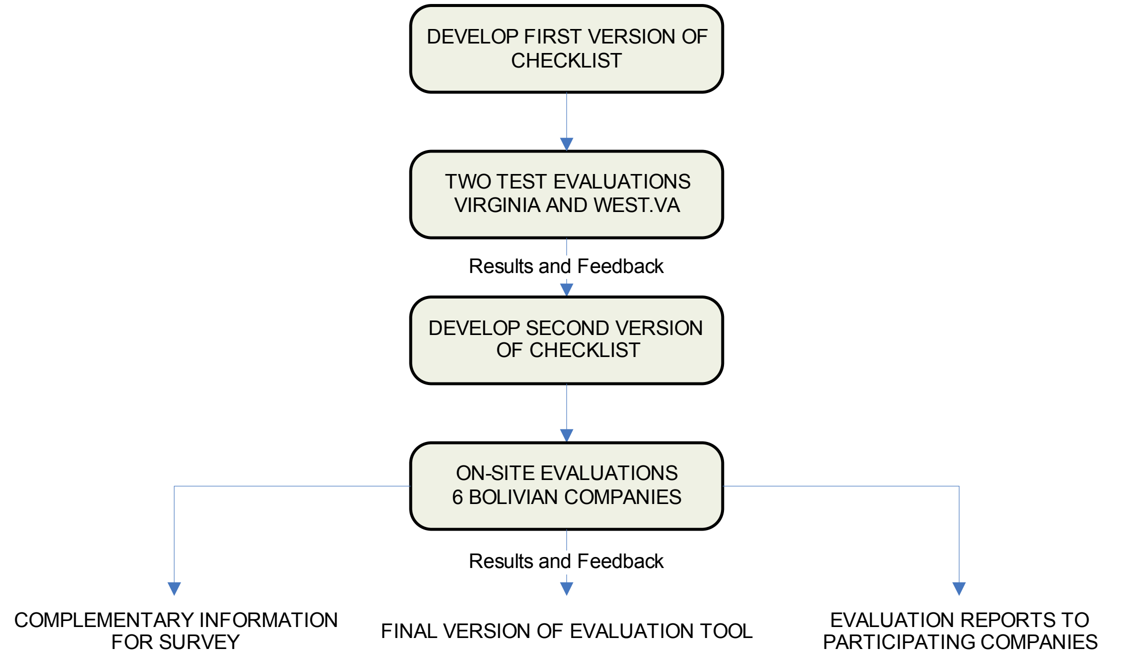

Figure 3-1. Outline for the development of the evaluation tool.

Quantitative indicators were used whenever possible, and it is required that personnel in charge of the evaluation are equipped with the following equipment in order to conduct the required measurements:

- Hygrometer
- Temperature sensors with data logger features
- Thermocouples
- Anemometer
- Electric moisture meter with external electrode
- Calipers, measurement tapes and level

A first version of the checklist was tested in two companies: one in Virginia and another in West Virginia. Some changes and corrections were made based on these trial evaluations. The final version can be found in Appendix B.

Once the second version of the checklist was ready, on-site evaluations were conducted in six Bolivian companies in December of 2006. The evaluations were conducted by the author of this document. Kiln operators answered the questions in all the companies and in two cases the production manager also participated.

Conducting the evaluations allowed the author to gather information regarding lumber drying practices which complemented and verified results of the survey; and develop information on how to further improve the evaluation tool. Four to six hours were necessary for each evaluation and kiln operators were very cooperative and interested in receiving input that may allow them to improve their knowledge and skills. After the visits, the results of the evaluations as well as suggestions for improvement were sent to the participating companies (an example can be found in Appendix D).

RESULTS AND DISCUSSION

The main component of the evaluation tool is the inspection checklist; it includes 6 sections and 94 inspections, and was designed using the formulary features of Excel to facilitate the input of data. Table 3-1 is a summary of the areas, individual drying components and assessment methods included in the checklist.

Table 3-1. Lumber drying components included in the evaluation.

Area	Sub-area	Question/Inspection	Method of assessment
General Information	General	Date of inspection, company name, location, main products, contact	Inquiry
Kiln information	General	Brand, capacity, age	Inquiry
		Type of construction	Inquiry/verification
		Energy source	Inquiry
		Control type	Inquiry/verification
		Loading type	Inspection
Kiln condition and maintenance	General maintenance	Existence of a maintenance plan and maintenance records	Inquiry/verification
		Leaks in doors, walls and roof	Inspection
		Drainage from kiln floor	Inspection
		Set points and actual conditions	Measurement
		Kiln response	Inquiry/inspection
		Condensation inside the kiln	Inspection
	Temperature and RH sensors	Type, number and location of temperature sensors	Inspection
		Frequency of wet bulb wick and EMC wafers	Inquiry
		Calibration of sensors	Inquiry
		Air speed across wet bulb	Measurement
		Water flow to the wet bulb	Inspection
	Steam valves and steam traps	Steam valves operation	Inspection
		Steam/water spray operation	Inspection
		Steam traps location and installation	Inspection
		Steam traps operation and maintenance	Inspection
	Air circulation system	Fan system type and conditions	Inspection
		Fan floor conditions and design	Inspection
		Fan reversal	Inspection
		Air speed check	Measurement
	Venting system	Vents type	Inspection
		Leakages in the venting system	Inspection
		Size and number of vents	Inspection
	Heating system	Type	Inspection
		Conditions of heating coils	Inspection
		Slope of heating coils	Inspection/measureme
		Insulation of steam lines	Inspection
	Humidification system	Type of humidification system	Inspection
		Humidification system conditions	Inspection

Table 3-1. Lumber drying components included in the evaluation (cont.)

Area	Sub-area	Question/Inspection	Method of assessment
Stacking practices	Stickers and bolsters	Stickers type, size and material type	Inspection/measurement
		Stickers moisture content	Measurement
		Stickers thickness uniformity	Measurement
		Stickers alignment	Measurement
		Stickers straightness	Measurement
		Missing stickers	Measurement
		Bolster thickness uniformity	Measurement
		Size of packages and sticker spacing	Measurement
		Stacking method	Inspection
		Side of packages	Inspection
		Lumber thickness variation	Inspection
		Bolster placement	Measurement
	Kiln loading and baffle use	Plenum space	Measurement
		Baffle use	Inspection
		Height of piles	Inspection
		Package placement	Inspection
Process control	General	Type o process control	Inquiry/inspection
		Process record-keeping	Inquiry/verification
	Sample boards	Number of sample boards/probes per load	Inquiry
		Selection of sample boards	Inquiry
		End-coating of sample boards	Inquiry/verification
		Sample boards length	Measurement
		Sample boards placement	Inspection
		Access to sample boards	Inspection
		Measurement of sample boards' MC	Inquiry
	MC measurement	Correction factors	Inquiry
		Operating temperature of oven	Inquiry/verification
		MC wafers dimensions	Inspection
		MC meters use	Inquiry/verification
	Auxiliary equipment	Oven, balance, band saw, anemometer and hygrometer	Inquiry/verification
Kiln operation	Drying schedules	Type of drying schedules	Inquiry/verification
		Source of drying schedules	Inquiry
	Target MC	Target MC determination	Inquiry
		Target MC values	Inquiry
	Mixed loads	Frequency of mixed loads	Inquiry/verification
		Species and thicknesses usually mixed	Inquiry/verification
		Moisture content previous to drying	Inquiry
	Equalization and Conditioning	Equalization methods	Inquiry/verification
		Conditioning methods	Inquiry/verification
Drying quality and degrade	Moisture content	Final moisture content of kiln samples	Measurement
		Final moisture content of lumber	Measurement
	Drying defects	Tensions	Inspection
		End checks	Measurement
		Surface checks	Measurement
		Warp	Measurement
		Other drying defects	Inquiry
Quality control and management		Drying objectives	Inquiry
		Value loss due to quality problems	Inquiry
		Drying and organizational structure	Inquiry
Drying storage		Dry-lumber storage facilities	Inspections
		Climate conditions in storage area	Measurement
		Climate conditions in manufacturing area	Measurement

If inspections are carried out using a computer, each question has an online help that is accessible just by placing the cursor on the question; also, each question has a hyperlink to another page with more in-depth information and benchmarks for good practices can be accessed by clicking on it. This is important for the recommendations phase of the process. Also, a summary of results is generated automatically for reporting and analysis purposes.

About the participating companies

Different company sizes, drying technologies, geographic regions and products categories are represented in the test group, as can be seen in Table 3-2. The participation of these six companies represent 29% of the total drying capacity in Bolivia (higher if we consider only companies that are currently operating); therefore, results from these evaluations give us insight into more technical aspects of lumber drying practices in Bolivia, information that would have been difficult to collect in a survey, such as the one presented in Chapter 1.

Table 3-2. Companies participating in test evaluations.

Company	Department	Number of kilns	Dryin Capacity (MBF)	Main Products
A	Santa Cruz	11	580	Garden Furniture
B	Santa Cruz	16	370	Garden furniture, millwork
C	Santa Cruz	10	430	Millwork
D	La Paz	5	140	Interior and garden furniture, millwork
E	La Paz	4	102	Flooring and furniture parts
F	Cochabamba	3	60	Millwork

All companies visited manufacture products for export markets, and their major clients are in the United States. Only one company sells a small part of its production to local market. Domestic demand for wood products is relatively small in Bolivia (0.07 m^3 in wood products per person per year, according to CADEFOR, 2002), and is usually served by small to medium-sized shops working on a made-to-order basis.

Half of the companies were manufacturing garden furniture, and, to some extent using FSC-certified wood. This market has experienced strong growth in the last few years since Bolivia has the biggest area of certified forest in the world (2.04 million ha as for December 2005, according to the Forest Stewardship Council).

Education and Training in Lumber Drying

Knowledge of lumber drying principles is highly variable among kiln the operators at the operations visited. Only in one company did the kiln operator have a college degree in a wood-related area. Lumber drying is usually taught as a specific course in Forestry Engineering programs in specific course or as a part of industrial processes courses, as can be seen in Table 3-3.

Table 3-3. List of educational institutions teaching lumber drying on a regular basis.

University/Institution	Location	Degree Offered	Lumber Drying Taught as
Universidad Autónoma Juan Misael Saracho	Tarija	Forestry Engineer	Course Wood drying and preservation
Escuela de Ciencias Forestales	Cochabamba	Forestry Engineer Associate Degree	Within course of Industrial Processes of Wood
Universidad Autónoma Gabriel René Moreno	Santa Cruz	Forestry Engineer	Course Wood drying and preservation
Universidad Privada de Santa Cruz	Santa Cruz	Industrial Engineer in Wood	Within course of Industrial Processing of Wood
Universidad Técnica de Beni	Beni	Forestry Engineer	Course Wood drying and preservation
CADEFOR	Santa Cruz		40-hour courses at the request of interested parties

Based on the observations made during the visits, the following sections report practices that were found to deserve a critical analysis or need improvement. Where appropriate, suggestions for improvements are proposed.

RESULTS OF COMPANY EVALUATIONS

Kiln Conditions and Maintenance

Maintenance of drying facilities and equipment was done reactively rather than proactively, and none of the visited companies keep proper maintenance records. In all cases, protective coatings to chamber walls were not applied since kiln installation. Most of the inspected operations were experiencing problems with their humidification systems, especially with water spray. Some operators modified the original kiln systems to meet their requirements.

Even if kilns were capable of automatic operation using probes, operators prefered to make schedule changes by themselves. This is probably a consequence of the lack of information on safe drying rates and standard schedules; or poor kiln performance after a few years of operation. All operators had stationary-mounted psychrometers in each kiln to compare readings from the control panel.

Air velocity varied greatly among the inspected kilns, with an average of 1.5m/s (300 fpm) and standard deviation of approximately 0.5m/s (100 fpm), which is considered appropriate for hard-to-dry or check-prone species (Denig et al., 2000) but rather low for white woods (like Ochoó and Bibosi). Since only one of the companies had variable speed fans in some of their kilns, the only way to overcome this limitation when drying easy-to-dry and stain-prone species is to experiment lowering the relative humidity.

Stacking and Loading Practices

Stacking practices were found to be fairly good (based on observations about sticker placement, sticker’s materials and conditions, and size of packages). Invariably, stacking and un-stacking is done manually - there are no mechanical stackers in Bolivia.

Stickers play two major roles in lumber drying: they provide a space for airflow between layers of lumber and – when properly used – help to reduce warp. Apart from being made of the appropriate material and profile, stickers have to be kept dry and straight, by storing them under shed and using proper racks for their handling (Simpson, 1991). Although no particular care in sticker handling was observed during the visits, in general they were found to be in good condition, perhaps because stickers are usually made of very dense species, like Cuta (*Phyllostylon rhamnoides*, specific gravity at 12% of 0.95), Almendrillo (*Dipteryx odorata*, 0.97) or Cuchi (*Astronium urundeuva*, 1.22). Sticker thickness variation, represented by the standard deviation of a randomly selected sample, was 1.22mm or below for most of the companies. Stickers' average moisture content was below 10% in all cases but one, where it was 14.2% (Figure 3-2).

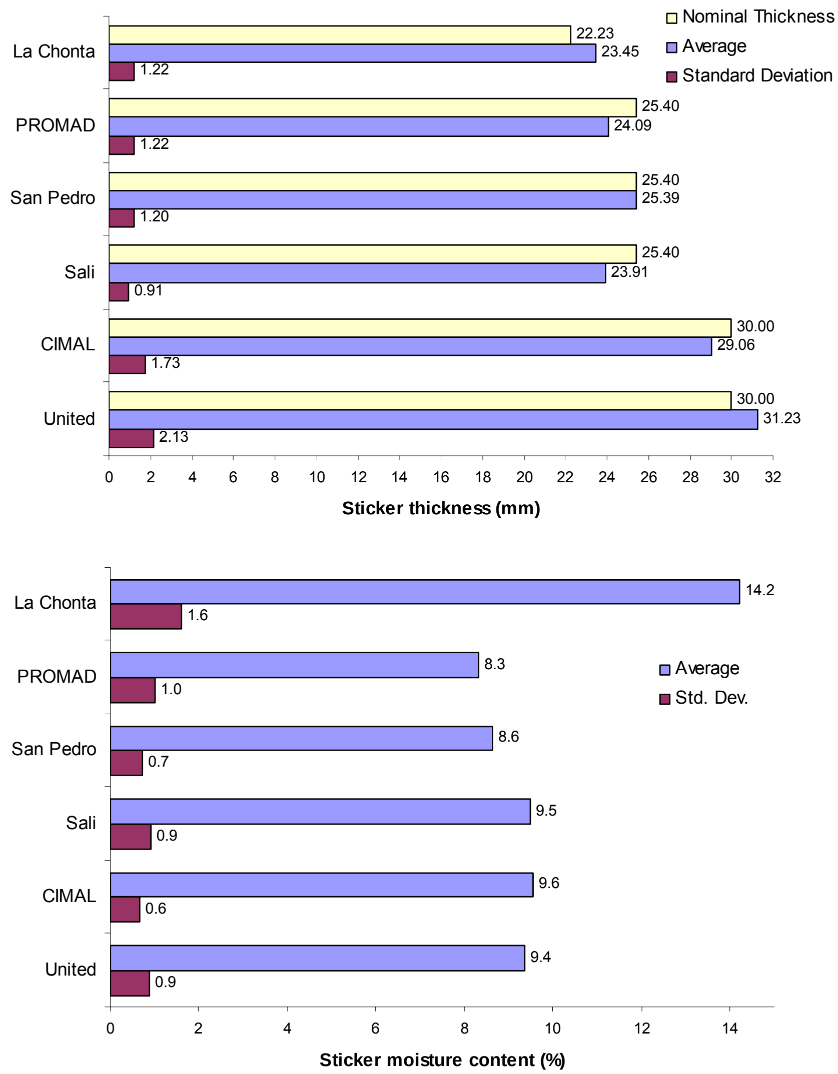

Figure 3-2. Stickers thickness and moisture content.

Sticker's dimensions merit some comments. Two companies were using 30mm-thick (1-3/16 in.) stickers for drying 2 in. lumber, as recommended in the Drying Manual of the Andean Pact. Since a 30mm-sticker reduces kiln capacity by more than 20% with respect of 19mm-stickers (Denig et al., 2000), the gains in drying rate and moisture content uniformity must at least offset the reduced throughput. To investigate this, the equation developed by Bois and Tschernitz (Bois and Tschernitz, 1981) was used to estimate the length of air flow path – the distance air flow travels through the lumber pile before becoming saturated – under some typical conditions observed during the visits. Two of the most commonly dried species were used in the calculations. Air speed was assumed 300fpm, daily moisture loss of 2% and wet-bulb depression of 4ºF (initial stages of drying). Results are shown in Figure 3-3.

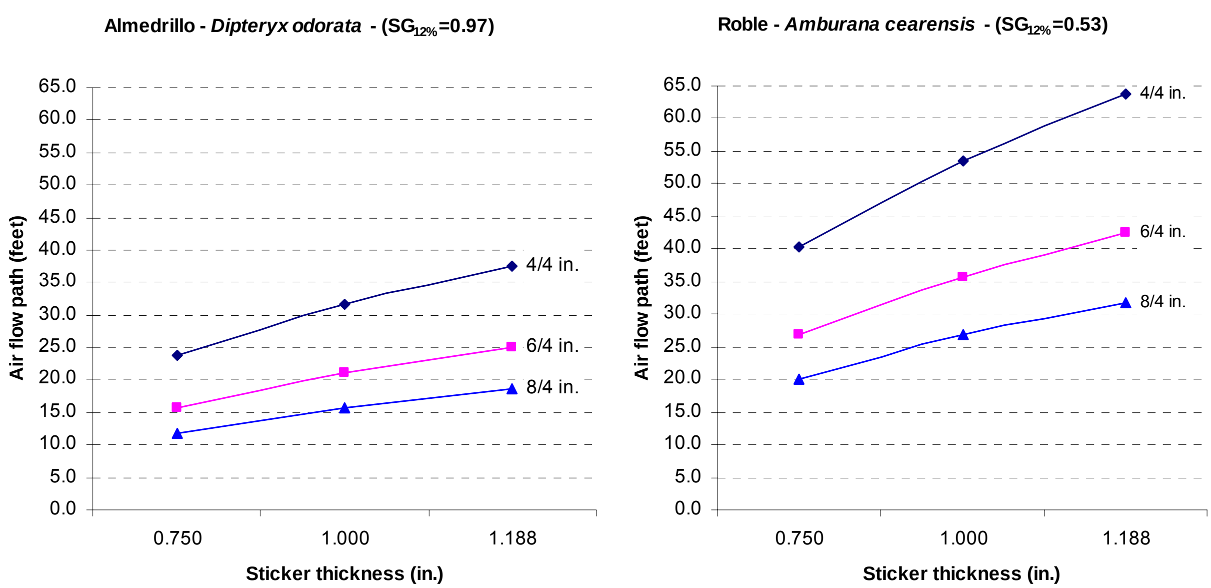

Figure 3-3. Air flow path for two Bolivian species.

As an example, a company drying 1.5-in.-thick Almendrillo (*Dipteryx odorata*) in a 24-foot wide kiln under the conditions shown in Figure 3-3 will find it difficult to get a uniform drying when using 3/4-in. stickers, because air becomes saturated at about 16 feet, or 8 feet before reaching the other edge of the pile. This problem is particularly important in some kilns without fan reversal, fairly common in Bolivia. On the contrary, using 1-3/16 in. stickers will allow airflow to reach the other end of the pile still unsaturated. The situation is worse when drying 2-in. lumber (air flow path of less than 20 feet even with 1-3/16-in.-stickers).

One company in Santa Cruz stacks white species by staggering stickers instead of aligning them in columns; this - according to the operator - prevents stain, a common problem in species such as Bibosi (*Ficus glabrata*), Ochoó (*Hura crepitans*) and Yesquero (*Cariniana estrellensis*). While the effectiveness of this practice is dubious, it is important to consider that the company also applies chemical treatment to white species and end-racks (placing boards upright and crossing each other forming an "X") the lumber until it looses some moisture, hence most probably the satisfactory results are not necessarily due to their stickering method.

Baffles serve the main purpose of directing airflow through the load, avoiding short-circuits and allowing uniform airflow (Simpson, 1991). This is especially true for package-loaded kilns, which because of their design are prone to variable loading (Bois and Tschernitz, 1981), and thus present more difficulties for proper baffling than track kilns. Home-made kilns in Bolivia usually do not have baffles and in commercial ones they were not being properly used.

Plenum space was close to what is recommended by theory in all cases (the sum of total stickers and bolsters openings; Simpson, 1991). In track kilns, by nature of their design, loading is better accomplished than in package kilns. Only one company was using restraints on the top layers of the load (to reduce warp) in the form of cables and turnbuckles (Figure 3-4).

Figure 3-4. Lumber stacking practices in Bolivia: (1) stacking different lumber lengths in a truck-kiln pile, (2) all stacking is made by hand, (3) using cables and turnbuckles to restrain the top layers of lumber.

Process Control

According to the survey results (see Chapter 2), all companies use moisture content to control the drying process. Three of the companies visited during the evaluations use sample boards to monitor moisture loss during drying and the remaining three use probes. Even though the companies using probes reported that 90% or more of its material comes green, they determine the initial moisture content using either the probes or a hand-held electric moisture meter, which can potentially lead to an over- or under-estimation of the initial moisture content and cause defects due to a poor selection of initial drying conditions - electric moisture meters are not accurate above 30% moisture content (James, 1988). Moreover, although operators acknowledged being aware of these differences, they were not making any effort to correct these readings.

Companies using sample boards to control drying were invariably end-coating samples with polyvinyl acetate adhesive (PVA). Some of them had switched from a tar-based coating to the mentioned adhesive, probably for availability and convenience of handling. The effectiveness of PVA as an end-sealer of kiln samples needs to be investigated. Rice et al. (1988) tested the use of polyvinyl acetate as a sealer to prevent surface-checking in drying oak; and found that in fact PVA performed well in reducing checking, especially when lumber is green, because it *slows* down surface moisture loss, but it does not prevent it, which should be the most important property of an end-coating for kiln samples. While thermal degradation in cross-linked PVA adhesive (the variety chiefly used in Bolivia) is well above the temperature ranges used for kiln drying in Bolivia (McNeill et al., 1995), it swells in when exposed to high humidity, which can lead the coating to loose it's sealing properties.

Regarding correction factors for moisture content readings, companies using probes for drying control select a "density class" - previously loaded in the control system by the kiln manufacturer - to correct moisture readings for species. However, none of the companies were using correction factors for species or temperature when using electric meters, which can lead to significant errors in moisture measurements, furthermore when they use electric meters to control moisture content uniformity in dried loads. Since none of the commercial meters have commonly dried Bolivian species in their database (with the exception of Mahogany), an alternative could be to use the regression equation developed by Minolta (1994), which estimates correction factors using the specific gravity. Its validity with tropical species was studied by calculating estimated factors using the mentioned equation and factors calculated experimentally for three tropical species of Brazil (Gillis et al., 1994), abundant also in Bolivia. Results of this comparison are shown in Table 3-4.

Table 3-4. Experimental and regression correction factors for moisture meters.

Species Commercial Name	Scientific name	S.G. at 12%	Meter reading (%)	Correction Factor for Capacitance-type Meters	
				Experimental method[1]	Regression method[2]
Cambará	*Erisma uncinatum*	0.63	12	-2.8	-2.9
Cambará Macho	*Qualea paraensis*	0.67	12	-2.9	-3.9
Paquió	*Hymenaea courbaril*	0.80	12	-4.9	-6.9
				p-value =	0.50

1 Gillis, C., Stephens, W. and P., Perry. *Moisture Meter Correction Factors for Four Brazilian Wood Species* . 1994.

2 Milota, M. Specific Gravity As A *Predictor of Species Correction Factors for a Capacitance-Type Mositure Meter* . 1994.

As can be seen, the regression equation provides a fairly good estimation of correction factors for these three tropical species, with increasing error at higher specific gravities. A table of correction factors for each species could be constructed and used to measure moisture content with a hand-held dielectric meter. Correction factors were calculated for the three most dried species dried in Bolivia. Results are shown in Table 3-5.

Table 3-5. Table for correction factors of MC readings for three Bolivian species.

Meter reading* (%)	Actual moisture content (%)**		
	Roble	Mara Macho	Yesquero
7	6.8	6.4	3.8
8	7.7	7.3	4.6
9	8.6	8.2	5.4
10	9.6	9.1	6.3
11	10.5	10.0	7.1
12	11.4	10.9	7.9
13	12.3	11.9	8.7
14	13.2	12.8	9.6
15	14.2	13.7	10.4
16	15.1	14.6	11.2
17	16.0	15.5	12.1
18	16.9	16.4	12.9
19	17.9	17.3	13.7
20	18.8	18.2	14.5
21	19.7	19.1	15.4
22	20.6	20.0	16.2
23	21.5	20.9	17.0
24	22.5	21.8	17.8
25	23.4	22.7	18.7
26	24.3	23.7	19.5
27	25.2	24.6	20.3
28	26.1	25.5	21.2
29	27.1	26.4	22.0
30	28.0	27.3	22.8

* Capacitance MC meter set at Douglas Fir and 70ºF

** Based on equation by Milota (1994):

$$CF = 8.77 + 0.249 \times MM - 15.86 \times SG - 0.620 \times SG \times MM$$

The values in Table 3-5 should be used as a first approximation to correct readings taken with a capacitance meter when no correction factors are available.

Kiln Schedules

As was mentioned in the previous section, there are no standard schedules for common Bolivian species. None of the kiln operators consulted knew the safe drying rate (the maximum daily moisture loss without development of drying defects) of commonly dried species or the maximum initial temperatures that can safely be used without drying degrade. Within the project funded by the Cartagena Accord (López et al., 1989) three generic drying schedules (soft, moderate and strong) were developed, and assigned to common species depending on their density; however, none of the operators in the companies visited seemed to be using these schedules.

All companies to some extent develop their own schedules by trial and error, sometimes based on a published one or from scratch. This method usually leads to conservatism and it was observed in fact that most schedules used have maximum temperatures of 55 to 65ºC (130 to 150ºF). The source of drying schedules can be illustrated by looking at some examples of how some companies find or develop their schedules, as was observed during the evaluation visits:

- One company was using a software developed in Spain, which selects a drying schedule based on several parameters - like density, type of schedule, severity, initial MC and type of kiln -; the operator then modifies the schedules thus obtained to their specific requirements.
- A garden furniture producer hired a Brazilian lumber-drying consultant to develop a specific schedule for Roble (*Amburana cearensis*). According to the operator, the schedule allowed them to reduce their total drying times significantly, but lengthened conditioning step.
- Two companies were using as a base the schedules found in a publication by BOLFOR (1998), which in turn lists the schedules of the U.S. Forest Service's publication (Boone et al., 1988).

Drying Defects

Although the evaluation checklist included an assessment of most common drying defects, only moisture content uniformity was assessed. Results are shown in Figure 3-5. One company had a particularly high moisture content variation (standard deviation of 3.3%); a probable cause for this is the schedule in use: starting drying at a high temperature (70ºC or about 160ºF) and maintaining it while increasing wet-bulb depression, creating big moisture gradients up front that were difficult to equalize later in the process. Also interesting is the fact that this operation was drying lumber for garden furniture to a moisture content of 7.9%, while two other companies - with the same product - were drying to 9.9%.

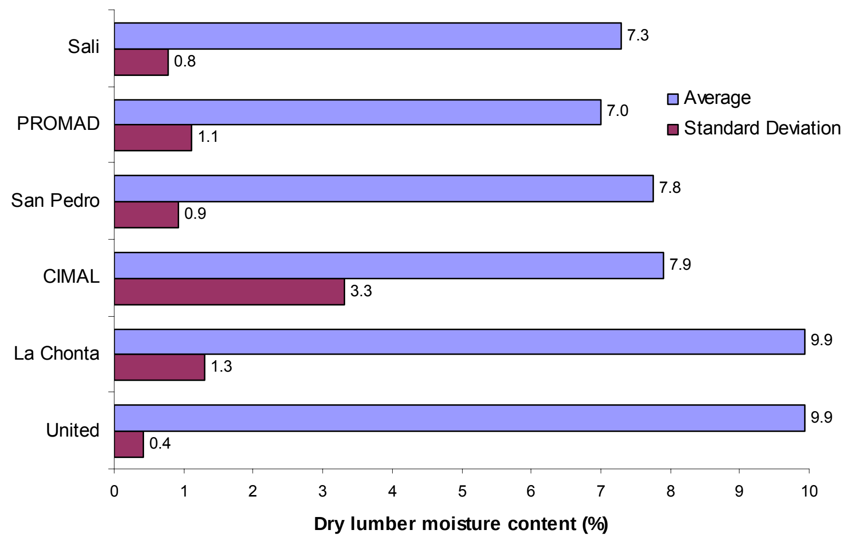

Figure 3-5. Moisture content uniformity.

Of particular concern when drying lumber for outdoor furniture or flooring, usually of high specific gravity, are surface and end-checks. End-coating green lumber is not a common practice in Bolivia and in locations like La Paz - where high winds and relative humidity of 25% are not uncommon - some of the lumber gets checked during storage and transportation.

Figure 3-6. Drying defects: (1) manual dip-soaking lumber, (2) mold and fungal stain in dried Bibosi (*Ficus glabrata*), (3) extensive end-checking in Almedrillo, (4) tension wood in Paquió.

Species like Ochoó (*Hura crepitans*) or Bibosi (*Ficus glabrata*) are susceptible of staining and are usually dip-soaked in an antifungal solution (typically sodium pentachlorophenate).

Some misconceptions regarding drying defects and methods to avoid them are common among Bolivian kiln operators. Regarding warp, it is generally believed that warp can be avoided with slow drying (usually at a high relative humidity), while it is documented that the reverse is true: a high relative humidity and air velocity reduce the occurrence of warp (Denig, 2000). It is also believed that checking can develop during the late stages of drying, and sometimes operators work at low temperatures when they notice surface or end-checking, even when moisture content is well below fiber saturation point.

Drying Storage

The most common type of dry lumber storage in Bolivia is open shed. No heated sheds exist. Sometimes lumber is covered with tarps to prevent checking caused by high winds, and a few companies plastic-wrap their most valuable lumber. (Figure 3-7). Storage temperature and humidity conditions are analyzed with more detail in the next chapter.

Figure 3-7. Storage of dry lumber: (1) shed with un-surfaced soil, (2) outdoor storage of tarp-covered lumber, (3) open shed storage, (4) plastic-wrapped packs of dry lumber.

Suggestions for Training Programs for Kiln Operators

Although training programs for kiln operators should include all the principles for effective and efficient drying, results of on-site evaluations discussed in previous sections have shown that emphasis is needed in certain specific subjects. Concentrating in these areas will allow future training to focus on areas that require improvement. Following is a list of suggested topics that need to be addressed in drying courses and seminars.

Wood-moisture relationships	Emphasis on the driving forces of drying: importance of air circulation, moisture content gradients development, temperature role and the influence of species characteristics. In-depth discussion is required on the strength of wood and how is affected by moisture content and temperature Dimensional changes in wood and differential shrinkage during lumber drying.
Kiln maintenance	Importance and main components of a maintenance plan, how to implement one. Function of each component of kiln equipment and facilities, especially baffles and humidification systems.
Electric meters and probes	Operational principles of dielectric- and resistance-type moisture meters. Useful range of electric meters. Importance of correction factor and how to determine them.
Drying defects and quality control	Causes for most common drying defects and how to prevent them. Metrics for the assessment of drying defects. Main components of a quality control program for lumber drying, its importance and how to implement one

THE EVALUATION TOOL

This evaluation tool was conceived as an efficient way to reach the entire industry, providing kiln operators and lumber drying consultants with a systematic way to have an assessment of the overall performance of the drying operation.

The set of analytical tools developed in this part of the project consists of a spreadsheet-based interface with a checklist, a results sheet and support information. The areas covered are listed with detail in Table 3-2.

The inspection checklist (Appendix B) can be printed out or used more efficiently with a portable computer. Each one of the 94 questions has a small help text, easily accessible as a screen text box with specific instructions to conduct the inspections. The questions are intended to be filled out by personnel with some familiarity with the drying process, i.e. the kiln operator, or a person specifically trained for this purpose.

A support information sheet is accessible from the checklist through hyperlinks in each question. This component of the valuation tool contains guiding principles for every aspect covered by the checklist and benchmarks to compare the parameters measured on the field. The information contained in this sheet comes from literature about lumber drying, namely: Kiln's Operator Manual (Simpson, 1991), Drying Hardwood Lumber (Denig et al., 2000), Dry Kiln Handbook (Bachrich, 1980), Kiln Drying of Sawn Timber (Hildebrand, 1970), and various scientific articles.

The results sheet automatically summarizes the results of the evaluations, listing the answers for each question and performing some calculations based on the measurements taken. Then, this information is combined with the support information sheet and the most important weaknesses are identified and actions for improvements can be suggested. For this last stage of the evaluation process, the participation of a person with basic knowledge regarding lumber drying practices is needed.

After the recommendations are implemented, or as established policy, the evaluation can be conducted again to assess improvement of the operation.

The evaluation process is depicted in Figure 3-8.

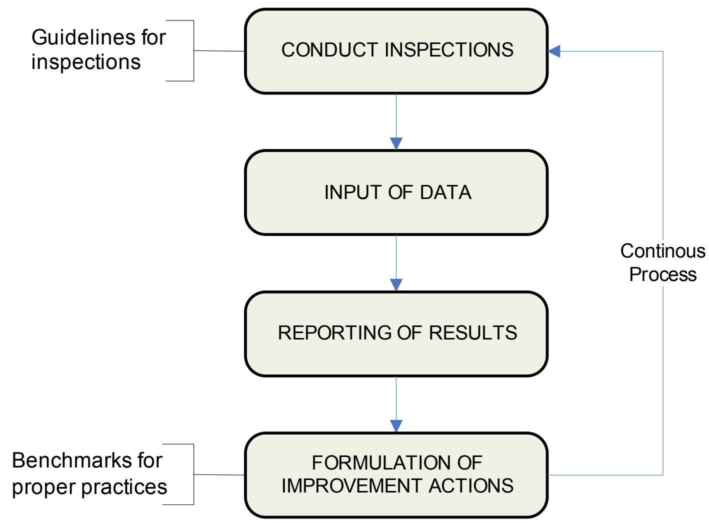

Figure 3-8. Evaluation process.

Although the interface for input and reporting of results makes the evaluation process easier, the participation of a person with knowledge of lumber drying principles is needed, especially in the analysis of results and the formulation of improvement actions. The interface can be better understood with an example:

Figure 3-9 shows the checklist interface, where the user inputs the results from the evaluation (this can be done directly when a laptop is used during the inspections), each question provides information about what measurements or observations have to be done. In the example, question B14 corresponds to the inspection of the plenum space in use.

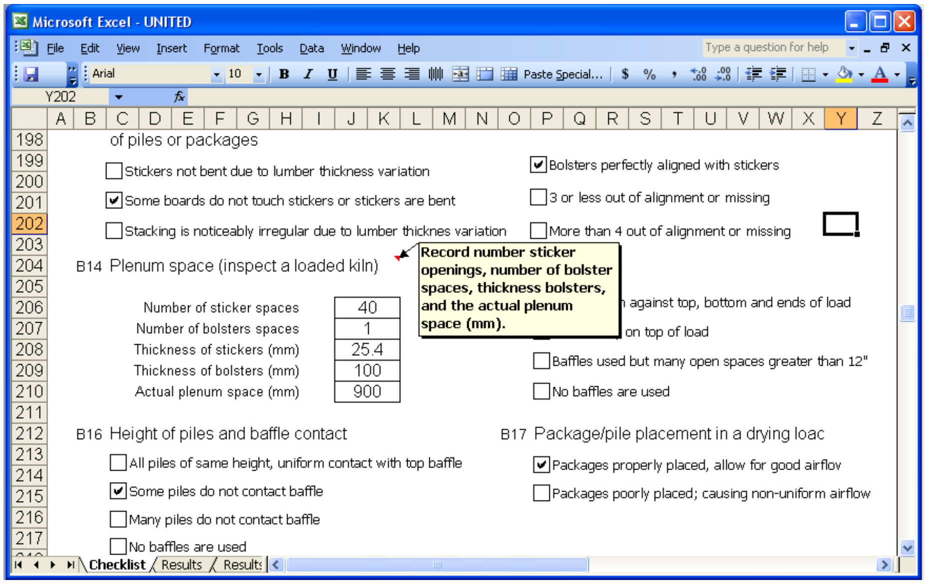

Figure 3-9. Checklist interface showing help windows for question about the plenum space.

A results sheet is automatically updated (Figure 3-10). In the example, the theoretical plenum space was calculated based on the measurements entered in the checklist (theoretical minimum plenum space of 1,116mm vs. 900mm measured on site).

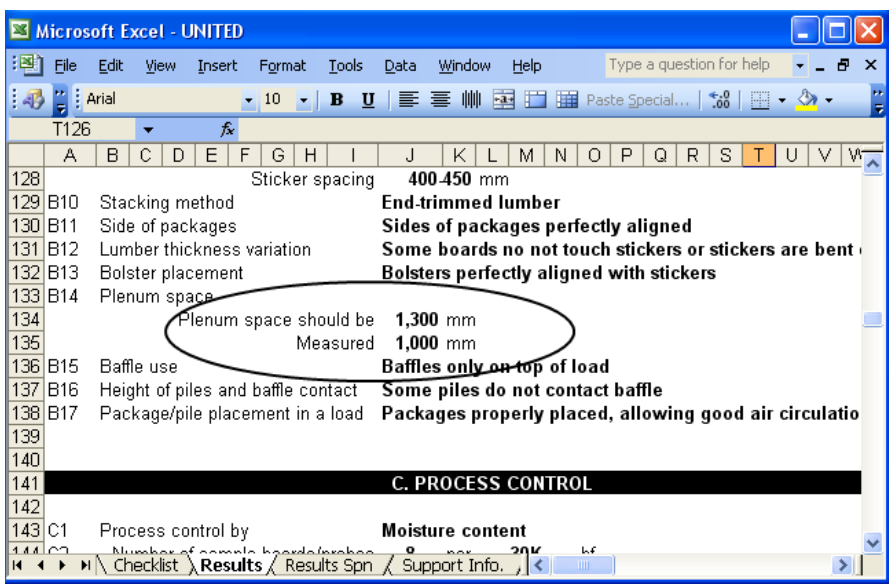

Figure 3-10. Results sheet.

Support information is provided for every question (Figure 3-11), and can be used in the formulation of an improvement action. In this case the plenum space needs to be increased in order to provide a more uniform airflow.

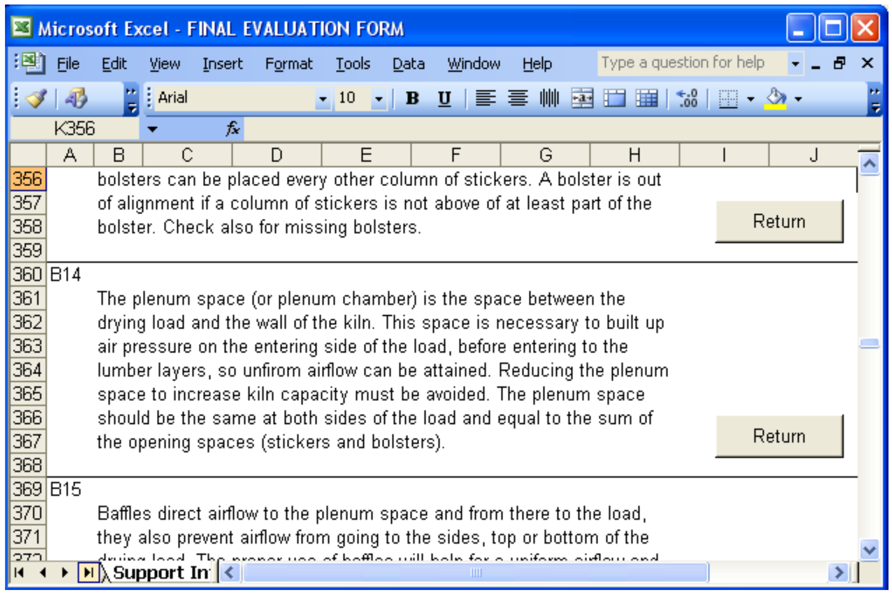

Figure 3-11. Support information sheet.

Although similar checklists contain information regarding good drying practices, the spreadsheet configuration makes this tool much easier to find and relate to specific questions and aspects of lumber drying. This feature also enables the evaluation tool to be used as an educational material.

Although the spreadsheet generates results automatically, it requires the participation of a person with basic knowledge of lumber drying to generate the recommendations. This done by combining the results and support information sheet that provides benchmarks for proper lumber drying practices. Further work could be carried out to automate the process using a more flexible programming language. The evaluation process can be carried out again in the same operation after changes were implemented to evaluate the improvement process.

The Spanish version of all the written and electronic materials that comprise the evaluation tool will be handed over to CADEFOR for its promotion and use (the Spanish version of the evaluation checklist can be found in Appendix C). It is considered that they have qualified personnel and close contact with the industry to put all these materials in practice.

CONCLUSIONS

An analytical tool for evaluation of lumber drying practices was developed and tested in the second part of the project. The tool consists of a checklist for on-site evaluations and a computer interface that assists the interpreter with developing a report with suggestions for improvement. A checklist covering the most important aspects of lumber drying was designed specifically for the Bolivian industry. Results of the inspections are generated by a spreadsheet-based interface and guidelines to run the evaluations and support information for all the areas being inspected are also provided.

In order to test the tool, on-site evaluations were conducted in six Bolivian companies, representing a wide range of technology, operation size, and drying practices. Selection of companies was based on the results of a previous survey of lumber drying operations. The visits also provided information about specific practices that complement the results of the survey regarding stacking practices, drying process control and kiln technology and maintenance aspects. These practices were critically analyzed and some suggestions for improvement are presented, as well as suggestions for future training programs for kiln operators and managers. Results of the on-site evaluations also indicated the need to include in the tool a component of support information, not initially considered.

Some limitations of the evaluation tool can be mentioned:

- The tool does not provide a quantitative rating of drying operations, and observed practices have to be compared against benchmarks provided in the support information. Also, the formulation of actions for improvement requires the participation of someone with knowledge of lumber drying principles.
- The results offer a general assessment of performance for the different hardware components of lumber drying, and do not deal in detail with technical issues; these need to be addressed by specialized personnel.
- Although the most important aspects of lumber drying were included, future use of the

tools could suggest the need to include more areas or individual components to be inspected.

As suggestions for future work, the evaluation tools presented can much be improved by automating the evaluation process with a more powerful programming language, thus eliminating the need of expert opinion in the recommendation phase. A ranking system could also be included to prioritize the needs for improvement.

The materials included represent a first attempt to provide an improvement specifically tailored to the Bolivian wood products industry's particularities and needs. It is believed that – in cooperation with the Bolivian institutions – the tools presented here can help in assessing the relative performance of individual lumber drying operations and thus provide a base to suggest actions for improvement in individual companies. Training programs for kiln operators can also be designed based on the results of the visits and future evaluations.

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CHAPTER 4 MOISTURE CONTENT CHANGE DURING LUMBER STORAGE, MANUFACTURING AND SHIPPING

ABSTRACT

After lumber is dried it is important to keep the moisture content as close as possible to its target value during all stages of production to assure product quality. Knowledge of climate conditions at all stages of the manufacturing process is essential to provide a good control of lumber moisture content. This study is the first step to provide Bolivian companies and institutions with information about the potential for moisture change during post-drying activities. This information is currently not available. To accomplish the objective of evaluating the potential moisture content gain/loss during processing of lumber and shipping of final products, temperature and relative humidity were monitored during lumber storage, manufacturing and containerized ocean-shipping and the equilibrium moisture content was calculated. Readings were taken between August 2005 and March 2006 in three Bolivian wood manufacturing plants, located in three different climatic regions. Measurements were also taken in three containerized ocean shipments of wood products to the U.S to determine how climatic conditions would affect equilibrium moisture content.

EMC measurements from storage and manufacturing areas showed important differences between equilibrium moisture content and lumber moisture content during post-drying stages. Depending on the geographical region and month of the study, differences between lumber MC and monthly average EMC were found to be from -1% to 7%. The biggest differences were found in La Paz and Santa Cruz where most of the industry is located, which represent the driest and wettest of climates. Difference between storage and processing EMC ranged from no difference to more than 3.6%, depending mainly on facilities design and region. Since differences of 2% moisture content have been shown to cause splits, cracks and warp, improvements in storage and manufacturing facilities are needed. Average monthly equilibrium moisture content values for the main cities in Bolivia were calculated

based on historic weather data and is also reported.

Differences between lumber moisture content and average equilibrium moisture content during ocean-transport ranged from 3 to 4%. Origin and month of the study did not appear to have a significant influence on average transport EMC, with only a 1% difference between shipments in different seasons of the year. However, only two origins and destinations were investigated in the shipping studies. Packaging materials and methods were determined to have an influence in the climate conditions inside packages, mostly by attenuating sharp changes in temperature and relative humidity, thus reducing the risk of condensation.

INTRODUCTION

Most of quality problems with solid wood products are caused by changes in moisture content (Eckelman, 1998). These changes occur when the equilibrium moisture content of the environment is different than the moisture content of wood. Wood, if left enough time, will gain or loose moisture until it reaches a moisture content equal or close to the equilibrium moisture content (EMC) of the prevailing ambient conditions. Moisture content changes lead to dimensional changes and can also cause problems gluing, machining, finishing and durability problems.

Dimensional changes are particularly detrimental in products assembled from numerous pieces and joints, causing splits in panels, end checks, cracks in the finishing coats, and open joints (Eckelman, 1998). If the product is exported unfinished or in parts, uneven or improper moisture content can cause problems during the finishing or gluing at the country of destination. This is why special care is needed to dry lumber to the proper moisture content and with minimum variations.

Once lumber is dried to the target moisture content, it undergoes several conversion stages before reaching the final customer, and very often each of these steps takes place in environments with different climate conditions. First, dry lumber is placed in a storage area, typically an open or closed shed, sometimes with heating to lower the EMC. The material is then moved to a manufacturing facility for its processing into final products, which normally takes place in a closed space, with environment controlled to some extent. Finally, products are shipped to a warehouse or directly to the final customer. In exports operations, products are typically shipped in multimodal containers, where temperature and humidity can take very high values, and change rapidly.

The time wood spends on each one of these steps varies with product, production scheduling, demand and distance to the final market. Depending on the time taken and the prevailing environmental conditions in a certain phase of the process, wood can gain or lose moisture, which in turn potentially translates in dimensional changes or biological attack, depending on the moisture range. It is common to attribute moisture-related problems to poor drying, without considering other steps in the process, but in order to address moisture-related problems, it is essential to know where the problems occurred.

In Bolivia, secondary operations present some peculiarities regarding this matter. Dry storage is usually done in open sheds, without environment control. During the rainy season, December-March, lumber acquisition is virtually impossible and companies usually stock large quantities to assure production continuity. EMC during these months can be as high as 16% in the eastern tropical region and then decrease to 11% during dry season. On the western side of the country; EMC's as low as 5% may exist during winter months (National Service of Meteorology and Hydrology of Bolivia, 2006).

Heated storage is not practiced and commonly consists of open sheds sometimes exposed to high winds and rain, as was observed during the on-site evaluations described in the previous chapter. Manufacturing activities are usually carried out under poorly controlled environments, chiefly open sheds without humidification or air circulation systems. Shipping of Bolivian wood exports is usually done in containers through Chilean ports, which takes several weeks to reach final destination. Temperature and relative humidity steadily increase as these containers approach the Equator line (Monohakobi Technology Institute, 2006).

However, it was observed that most kiln operators and managers do not take prevailing climate into consideration when making decisions about target moisture content, dry-lumber storage or packaging of final products. Lumber is dried to approximately the same target moisture throughout the country: typically 7 to 8% for indoor products and 11-12% for outdoor furniture, as observed during the on-site visits described in the previous chapter.

It is in this view that the objective of this study was to evaluate the potential moisture content change during lumber storage, manufacturing and shipping of final products by collecting climate data during these steps of the production process. This information can be used by the industry to identify potential causes of moisture-related problems, determine target moisture content, and design of packaging, storage and manufacturing facilities.

The target moisture content to which wood is dried chiefly depends on product category and its service conditions. Wood poles are dried to 30 to 50% MC, depending on the species, and usually only targeting the sapwood portion to attain a reasonable preservative distribution (Utility Pole Research Cooperative, 2005). Construction lumber must not exceed 19% or 15% MC (NDS, 2001). Upper grades of softwood lumber is dried in a way that 85% or more of the pieces are at or below 12% MC, and no piece should exceed 15% MC (Kozlik, 1994).

Lumber used to manufacture furniture or millwork for interior use is dried to typical values of 6 to 11% MC (Denig et al., 2000), depending on the final location, and with narrow tolerances because dimensional changes in these products cause more detrimental effects, like loose joints in furniture and millwork and splits and checks in table tops (Eckelman, 1998). As and example, for a 76.2-mm (3 in.) wide piece of northern red oak, a 3% change in moisture change can cause a change in width of 3.6 to 8.4mm (0.14 to 0.33 inch), depending on the grain orientation (Denig et al., 2000). The general rule is to dry lumber to the EMC of the service conditions, midway between the expected highest and lowest EMC (Forest Product Laboratory, 1973).

Wood changes its moisture content according to the relative humidity and temperature of its surroundings, which in turn change with season of the year and daily. Short-term changes cause only moisture variation in the surface (Forest Product Laboratory, 1999), but long-term changes (seasonal) are more enduring and reach deeper into the cross-section.

Moisture Changes during Storage

Once the target moisture content with small variation across the load has been attained, moisture content gains during further steps of the process should be kept at minimum. Many methods have been proposed to maintain moisture content in stored dry-lumber; probably the most widely used today consists in heating the storage space certain number of degrees above the ambient temperature (Simpson, 199l and Elkins, 1974). Figure 4-1 shows a chart that can be used to determine the degrees above ambient temperature that a closed environment needs to be heated in order to reach the desired equilibrium moisture content (Simpson, 1991).

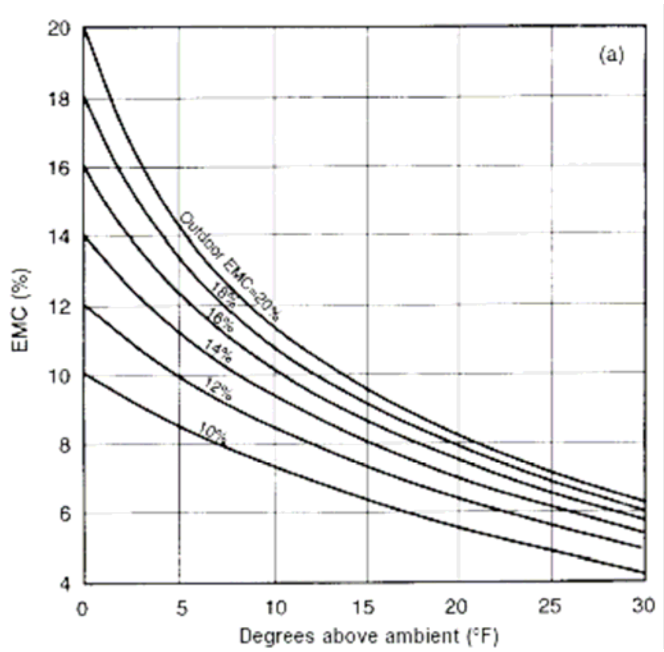


Figure 4-1. Degrees above ambient temperature to heat a closed environment for a desired EMC (Simpson, 1988).

The previous and two other methods for EMC control were evaluated by Peralta and Bangi (2005), namely: keeping temperature at a constant value above the morning minimum or the dew point ("thermostat" method), and adjusting temperature according to a desired relative humidity ("humidistat" method). The "humidistat" method showed to provide best control of EMC, with a low relative deviation from target value.

Another method for controlling moisture gain or loss during storage is the use of lumber wrapping in various materials, like paper or plastic-based covers (Keey et.al., 2000). Applefield (1966) reports moisture gains during a 6-month study ranging from 4.9% for lumber wrapped with Kraft paper to 11.2% for polyethylene-wrapped lumber. Another research (Keey at al., 2000) carried out in New Zealand showed moisture content gains of 0.5% using plastic film and 2.3% for a paper-based wrap during a 16-week study and inside an open shed storage. While these methods do not completely prevent moisture pick-up, they provide a way to retard it, especially when lumber is stored in open sheds or during shipping.

A series of experiments carried out in Vancouver, British Columbia aimed at estimating moisture changes of lumber during storage and shipping (Forest Products Laboratories Division, 1952). The study showed a marked difference in rate of moisture adsorption between lumber stored in open sheds and heated, closed shed. Moisture change shortly after drying was rapid, especially moisture gradient, as was also observed by James et al. (1984). Lumber stored in open sheds, reached moisture contents as high as 18.8% (from approximately 5% initial MC), while maximum moisture content of lumber stored in closed, heated shed was 10.7%. Rate of adsorption also depended on lumber thickness, species and time of the year. Moisture gradients within the piles were also developed, with boards in the center not absorbing as rapidly as those in the outside of the piles. Data from this study was used to construct a chart shown in Figure 4-2; EMC was calculated based on seasonal averages in Vancouver and is also included in the chart.

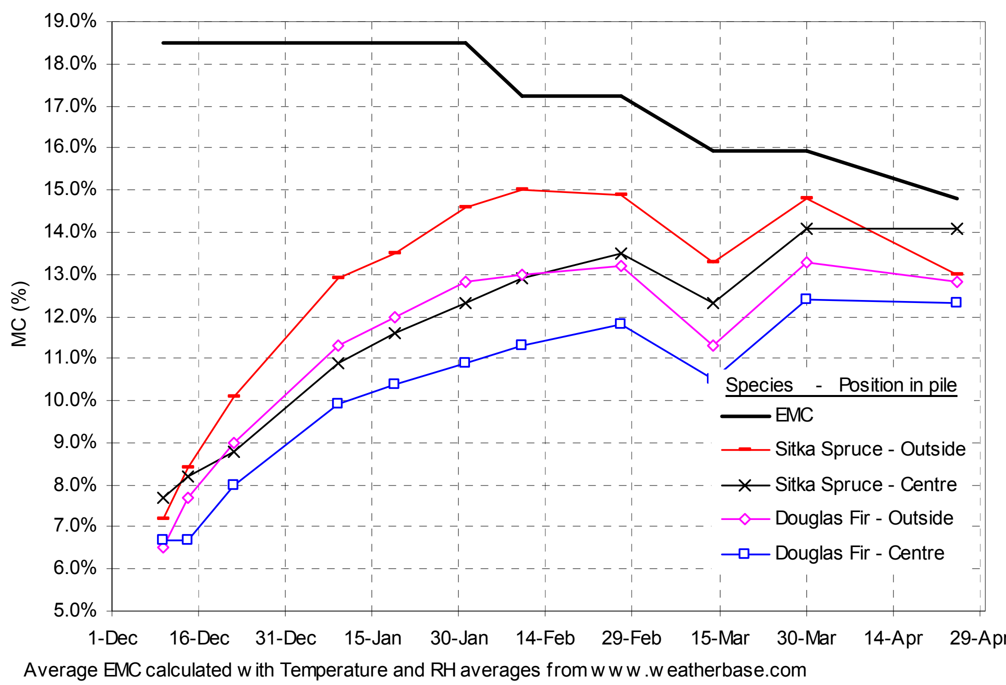


Figure 4-2. MC changes of 1x4 kiln-dry lumber, close-piled and stored in an open shed, as determined by the Canada's Forest Products Laboratories Division (1952).

New technologies have allowed researchers to better understand moisture adsorption distribution in a lumber pile. Moisture gradient development in a dry-lumber pile was investigated by Zhang (2005), making use of wireless radio frequency electric probes to monitor the moisture content change distribution in a lumber package placed in a humid environment (EMC of 16%) during 19 weeks. Maximum moisture content gain occurred in the top layer and the driest were located in the center of the layer located 1/3-height from the bottom (4.8 and 1.5%, respectively). An absorption equation was also developed to fit the data from this particular experiment. This equation was used to generate the following graph (Figure 4-3), which shows the moisture content as function of time and for boards located at three pile-heights and at the un-coated end. Notice that boards in the top layer follow about the same adsorption curve of a free-standing piece.

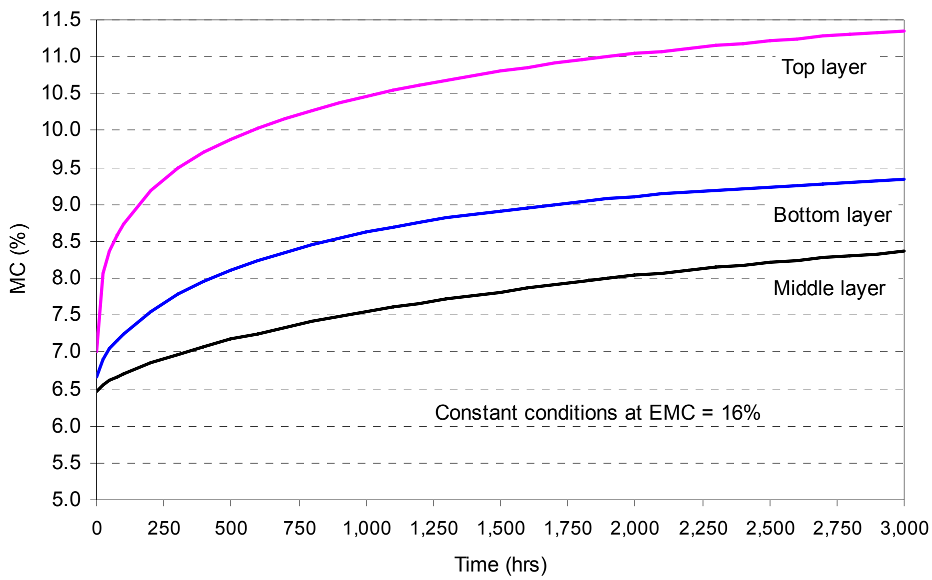


Figure 4-3. Moisture content as a function of time and position in a close-stacked pile of lumber, as determined using equations developed by Zhang (2005).

Moisture Change in Transport

Regarding moisture content change during transport, studies carried out by the U.S. Forest Products Laboratory and the Canadian Western Forest Products Laboratory to investigate the moisture change when lumber is shipped in tight railroad cars showed gains of less than 1%

(Forest Service, 1978).

Moisture change in 34 ocean shipments of lumber to 6 destinations was investigated in Canada (Forest Products Laboratories Division, 1952). Moisture change of kiln-dried lumber shipped by ocean ranged from -0.1 to 3.8%, depending on final destination, lumber thickness and stowage method (closed stowage or deck-loaded, respectively).

Conditions inside inter-modal containers can be particularly detrimental for wood products; temperature inside a freight container can reach 30ºF (16ºC) above outside ambient conditions (Forest Products Laboratory, 1979). Climate inside containers while on vessel chiefly depend on location in the deck (whether containers are carried “topstow” or “sidestow”), the effect of sunlight and ambient temperature (Monohakobi Technology Institute, 2006). Temperature and relative humidity in the interior of cargo containers invariably rise when the vessels transit the equator line.

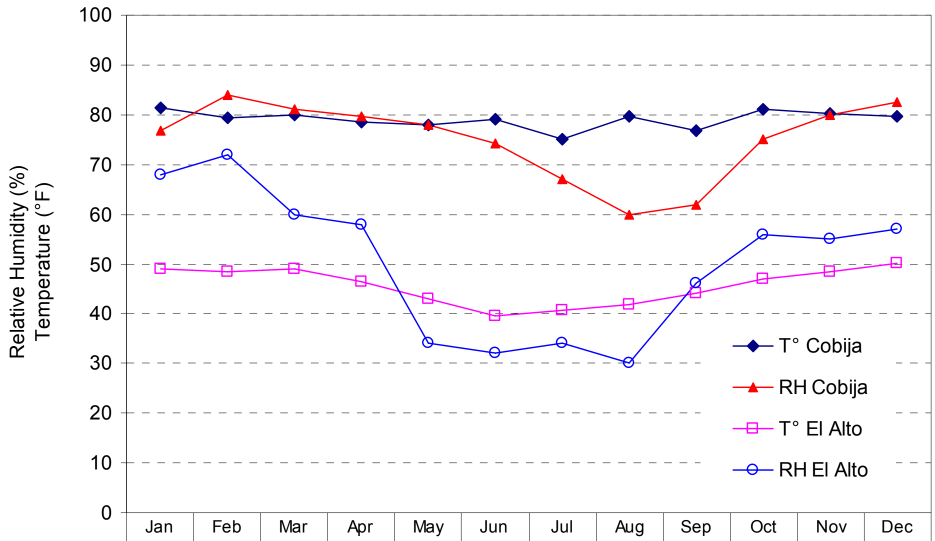
Another risk associated with shipping is condensation. Condensation occurs whenever the temperature of the outside corresponds to the dew point of the inside, and the air near the walls saturate and consequently condensate, with the potential of damaging the packing materials and the products. Condensation during tight, containerized sea-shipping is not a significant risk for products made of lumber at relatively low moisture contents (e.g., 7-9%) because they can hardly contribute moisture to the climate inside the container; but some Bolivian wood products like decking are sent at higher MC’s or even green. A study about condensation in containerized cargo shipped through the Hamburg-Australia route (Knobbout, 1972) showed that, condensation can be prevented by avoiding temperature differences within the cargo and by isolating the cargo that can emit moisture with special packing; also, there is more chance of condensation within the cargo when transported from a cold to a warm zone. Other containerized shipping studies (Ostrem, 1971) showed that maximum temperatures always occur inside containers on-deck and maximum relative humidity is very close to saturation.

Thus, even if the lumber is dried to a proper MC with minimum variation, it can gain or loose moisture during processing or shipping, with the consequent dimensional changes and associated problems (Eckelman, 1998).

Research about storage and shipping has shown that unless conditions are controlled (i.e. a heated, closed shed), kiln-dry wood will invariably pick some moisture from the environment. However, even in the case of lumber packs under constant conditions of temperature and relative humidity, studies show that moisture gain is rather a complicated phenomenon. Gradients are generated within a unit load and also in the cross-section of individual pieces; moreover, the rate of adsorption of individual pieces follows a different pattern depending on the location in the package. Also, rate of adsorption will depend on thickness, specific gravity, initial moisture content, piece geometry and piling method.

Drying in Bolivia

Drying facilities in Bolivia are located in three geographical zones of the country, each one with different weather conditions. Altitude ranges from 300m (980 ft.) above sea level in Cobija (department of Pando) to 4,000m. (13,400 ft.) in El Alto (La Paz). Prevailing climate in these locations vary greatly as well. Figure 4-4 shows the average monthly conditions in Cobija and El Alto. A very high relative humidity like the one found in Cobija, for example, can slow-down the drying process and contribute to the development of stain in some species. On the other hand, combined low humidity and high winds in El Alto can cause surface- and end-checks in stored lumber or final products.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T° Cobija	81	79	80	79	78	79	75	80	77	81	80	80
RH Cobija	77	84	81	80	78	74	67	60	62	75	80	83
T° El Alto	49	48	49	46	43	40	41	42	44	47	49	50
RH El Alto	68	72	60	58	34	32	34	30	46	56	55	57

Source: Temperature and Relative Humidity data from the National Meteorology and Hydrology Service (SENAMHI)

Figure 4-4. Monthly averages of temperature and relative humidity in selected Bolivia cities.

Tropical woods, with high extractive content and relatively high densities generally shrink and swell in a less predictable pattern (Siau, 1995). Table 4-1 shows densities of the ten most abundant species in Bolivia; note that half of them have densities of more than 0.9 g/cm^3. Most of the lumber dried is 2-inch thick and have relatively great widths, which add up to the complexity of the process (Rice, 1988).

Table 4-1. Density of most abundant species in Bolivia.

Commercial name	Density at 12% MC (g/cm^3)*
Ochoó	0.55
Almendrillo	0.97
Mara Macho	0.55
Bibosi	0.59
Verdolago	0.95
Yesquero	0.68
Cuchi	1.22
Curupaú	1.03
Tajibo	1.05
Cambará	0.57

* From Gutiérrez and Silva (2002)

Exports of Bolivian wood products usually are shipped in containers and sent on trucks to ports in the Chilean coast, which takes from 1 to 3 days; then containers are then loaded on vessels where they may stay from 15 to 45 days, depending on the final destination.

Unfortunately, it is difficult to estimate the losses caused to the industry by moisture-related problems, since this information is usually not recorded; but it is believed that, together with capacity constraints, dimensional change is one of the major causes for quality claims in the Bolivian wood industry.

No information was found on equilibrium moisture content in Bolivian locations, and on-site evaluations showed, with some exceptions, that kiln operators normally do not consider the prevailing climate when they establish target moisture content or storage practices. It is believed that a first step in assessing quality loss due to moisture content change during storage, manufacturing and shipping is to collect equilibrium moisture content information in different plants in Bolivia and during overseas shipping. This information will be available to the industry for its use in determining target moisture content and improvements in storage and packaging methods.

METHODOLOGY

To evaluate the moisture content change during the processing of lumber and shipment of products, the relative humidity and temperature were recorded in manufacturing plants at different locations in Bolivia and in containerized shipments from Bolivia to the United States. The underlying assumption is that, if left enough time, wood will approach the average equilibrium moisture content of the prevailing climate conditions. The methodology used for the studies is shown in Figure 4-5.

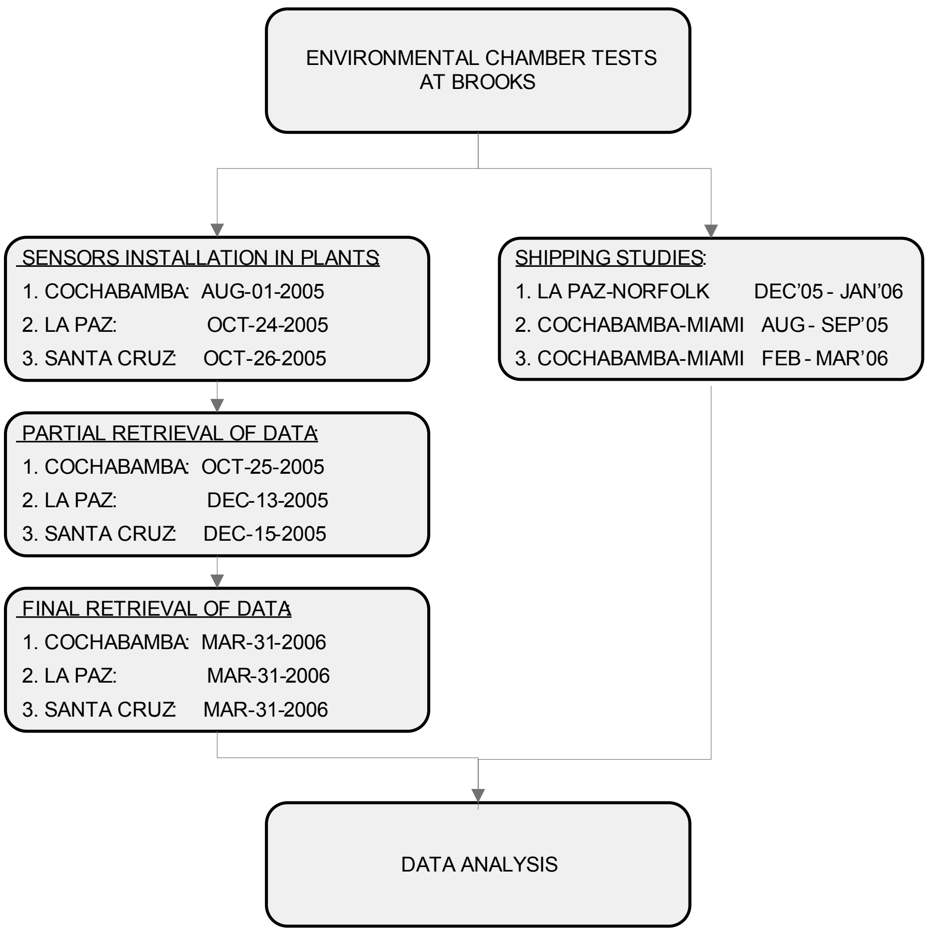


Figure 4-5. Outline of the methodology for EMC studies.

Sensors of Temperature and Relative Humidity

The sensor used for the study was the OM-43 from Omega (technical specifications can be found in Appendix E). These sensors, also referred as “data loggers”, are capable of taking temperature and relative humidity measurements for up to one year at programmable frequencies. A test was conducted in an environmental chamber under controlled conditions to determine the consistency of the readings taken by the different sensors. Data loggers arrived in two shipments and two one-week-long tests were conducted in the environmental chamber at the Brooks Center Laboratory in Blacksburg. Results are shown in Table 4-2.

Table 4-2. Results of test in environmental chamber for temperature and relative humidity measurements taken by data loggers.

ENVIRONMENTAL CHAMBER TESTS									
TEMPERATURE (°C)					RELATIVE HUMIDITY (%)				
FIRST TEST (Temp = 19ºC, RH = 69%)									
Logger	Range	Average	Abs.Error	Tukey's	Logger	Range	Average	Abs.Error	Tukey's
U 715947	0.39	19.43	0.43	A	U 491419	3.4	72.2	3.2	A
U 491424	0.39	19.42	0.42	A	U 491424	3.2	71.5	2.5	B
U 715948	0.39	19.42	0.42	A	U 594708	2.8	69.7	0.7	C
U 491419	0.39	19.43	0.43	A	U 715948	2.8	69.6	0.6	D
U 594708	0.39	19.43	0.43	A	U 715945	2.7	69.0	0.0	E
U 715945	0.38	19.35	0.35	B	U 715947	3.0	68.0	1.0	F
SECOND TEST (Temp = 20ºC, RH = 65%)									
Logger	Range	Average	Abs.Error	Tukey's	Logger	Range	Average	Abs.Error	Tukey's
U 916607	0.69	19.79	0.21	A	**U 491419**	**4.80**	**70.39**	**5.39**	**A**
U 491419	0.69	19.78	0.22	A	U 594708	4.80	67.07	2.07	B
U 594708	0.69	19.78	0.22	A B	U 916607	4.80	66.91	1.91	B
U 916601	0.69	19.77	0.23	A B	U 916600	5.00	66.27	1.27	C
U 916602	0.69	19.76	0.24	B	U 916601	4.80	65.58	0.58	D
U 916605	0.69	19.71	0.29	C	U 916602	3.80	65.50	0.50	D E
U 916600	0.69	19.43	0.57	D	U 916592	3.80	65.39	0.39	E
U 916592	0.69	19.43	0.57	D	U 916605	3.60	63.35	1.65	F

The selection criteria consisted of finding statistical differences among individual sensors and then evaluating departure from the nominal accuracy range (± 5% for relative humidity and ±0.7°C for temperature). Only sensor U491419 (shown in bold) showed readings of relative humidity out of the accuracy range and was therefore discarded.

Estimation of equilibrium moisture content (EMC)

The moisture content wood attains when in equilibrium with the relative humidity and temperature of the surrounding air is called equilibrium moisture content (EMC) (Siau, 1995); EMC can be estimated by looking at double-entry tables for different values of temperature and relative humidity (or temperature and wet-bulb depression). Its value is mostly dependent on relative humidity but also affected by temperature. The equilibrium moisture content can also be estimated using the following equations (Forest Products Laboratory, 1999):

$$EMC = \frac{1{,}800}{W}\left[\frac{Kh}{1-Kh} + \frac{K_1K\,h + 2K_1K_2K^2h^2}{1+K_1Kh+K_1K_2K^2h^2}\right]$$

$$\begin{aligned} &Where: \\ &\quad W = 330 + 0.452T + 0.00415T^2 \\ &\quad K = 0.791 + 0.000463\,T - 0.000000844\,T^2 \\ &\quad K_1 = 6.34 + 0.000775\,T - 0.0000935\,T^2 \\ &\quad K_2 = 1.09 + 0.0284T - 0.0000904\,T^2 \end{aligned}$$

Equation [4-1]

Where h is relative humidity in percentage and T is temperature in ºF, and K, K_1 and K_2 are diffusion coefficients developed by Hailwood and Horrobin (1946).

The studies implied thousands of reading of temperature and relative humidity, which were used to estimate the equilibrium moisture content, looking at tables or performing calculations by hand was impractical; thus, a custom function was created using Visual Basic for Applications in an Excel spreadsheet, and it was used as any built-in function. The Visual Basic code is listed in Appendix F.

Moisture Content Gain during Storage and Manufacturing

The moisture content change during processing and storage was evaluated by monitoring temperature and relative humidity in three facilities located in the main geographical regions: Santa Cruz, Cochabamba and La Paz. Based on weather historic data and importance of each city on wood products exports, these three cities give a good representation of extreme conditions that can be found among Bolivian industries.

For each company, one sensor was installed in the dry lumber storage area and two inside the manufacturing plant. The main reason to place two sensors in each plant was to identify differences between zones, namely machining (rough mill, shaping and gluing) and finishing (belt-sanding, hand-sanding and quality control). It is important to note that all zones in the plants of the study were enclosed in the same environment (i.e. same building), typical of Bolivian operations.

Before installation, all data loggers were enclosed in boxes to protect them from hits, excessive dust and from water coming from leaks in roofs. One-inch holes were drilled in boxes to make sure the temperature and relative humidity is the same as the ambient conditions (Figure 4-6). The data loggers and their protective boxes were placed at a minimum height of 8 feet to protect them from damage.

While a time span of 12 months would have been best to represent all possible conditions during the year, time constraints of the project allowed taking reading only during 5 and 8 months. Sensors were installed in early August in Cochabamba and in late October in Santa Cruz and La Paz. A partial retrieval of data was performed in October and December to verify the proper functioning of the sensors and final data was downloaded in late March of the next year.

Readings were taken every 1.2 hours, making up a total of 20 readings a day. This recording rate provided a good representation of changing conditions during a day and was one of the preset frequencies in the sensors. Equilibrium moisture content was then calculated for all the readings of temperature and relative humidity using the spreadsheet’s custom function.

Figure 4-6. Location of temperature and humidity sensors in: (1) storage facilities in Santa Cruz, (2) flooring and furniture parts plant in La Paz, and (3) protective boxes and door plant in Cochabamba.

Moisture Content Gain during Shipping

Moisture change inside a container is dependant on numerous factors, such as location within the load, distance from the container walls, packaging method and initial moisture content of the material (Knobbout, 1972).

The moisture content change during shipping inside cargo inter-modal containers was investigated by installing data loggers inside three shipments of wood products to two destinations in United States. Two sensors were installed in each shipment, one inside the packages and another outside, to investigate if packaging method had an influence in climate conditions inside the unit loads. The frequency of measurements in this case was 30 minutes, shorter than for the plant studies to notice differences between inside and outside conditions.

The packaging materials and methods were similar in all three cases: first, wrapping the product with stretch-plastic, then covering it with corrugated cardboard and finally using plastic or metal straps to hold the package together. However, in the first shipment, the top and bottom of the packages were not plastic-wrapped, since this was not common practice in the company of the study. For the next two studies the companies were requested to entirely wrap the product – including top and bottom - with plastic to identify if this has any influence in the inside package climate conditions.

The first and third shipment consisted of solid-wood exterior doors from Cochabamba to Miami and the second were solid-wood furniture parts and flooring from La Paz to Norfolk and then to Michigan.

Figure 4-7. Data logger placement for solid doors shipping study: (1) sensor inside package, (2) doors package inside container, (3) door pallet ready for shipment, and (4) outside sensor's in protective box.

Analysis of Data

The collected data was analyzed by first calculating EMC using the custom-function developed in Excel and differences between the locations where the sensors were placed. For the storage and processing studies EMC were averaged by day and month and presented in X-Y charts, the former to determine differences between the different locations and the later to identify possible trends from month to month. Maximum, minimums and averages were calculated for the calculated differences between sensor locations.

The shipping climate data was presented hourly, to identify trends between and within days. Also, maximum, minimums and averages were calculated for temperature, relative humidity and equilibrium moisture content.

A model to predict moisture gain under the conditions of the studies is not available, and its development would require considering the specific products, stacking methods, species, seasonal and hourly variations; thus potential moisture change was inferred combining the information found in literature and the results found in the study. The most important indicator to assess potential MC change is the difference between the estimated moisture content of the lumber or wood products and the equilibrium moisture content of the environment. Thus, the greater this difference the higher the risk of moisture content change in lumber or wood products.

Research recommends to control EMC in a way that it is as close as possible to the lumber’s MC (Peralta and Bangi, 2005; USDA Forest Service, 1989; and Forest Service, 1978). However, Wengert (1988) suggests that for practical purposes, if environment conditions are controlled within a difference of ±2% between lumber MC and EMC, significant problems caused by moisture content changes are not likely to occur.

RESULTS AND DISCUSSION

Storage and Plant EMC Studies

Cochabamba

Daily averages of EMC values for manufacturing and storage areas are shown in Figure 4-8. EMC values were calculated from temperature and relative humidity readings taken between August of 2005 and March 2006. The chart also shows differences between plant and storage Conditions in the three locations are, from a practical standpoint, equivalent (the average difference is only -0.1% and 0.2% for the two plant locations). This is not surprising considering that both dry-lumber storage and processing areas have a three-walled open-shade configuration in this company and the EMC profile follows that of the outside environment. However, this is in contrast to U.S. manufacturing locations, where EMC values can vary as much as 5% from outside conditions and 7% from different interior locations.

Readings were only taken up to the 145th day, because these data loggers were sent inside a container for the shipping study. Peaks in EMC correspond to days with rain as recorded by the national weather service. Notice that EMC scale in the graph starts at 5% to emphasize the differences.

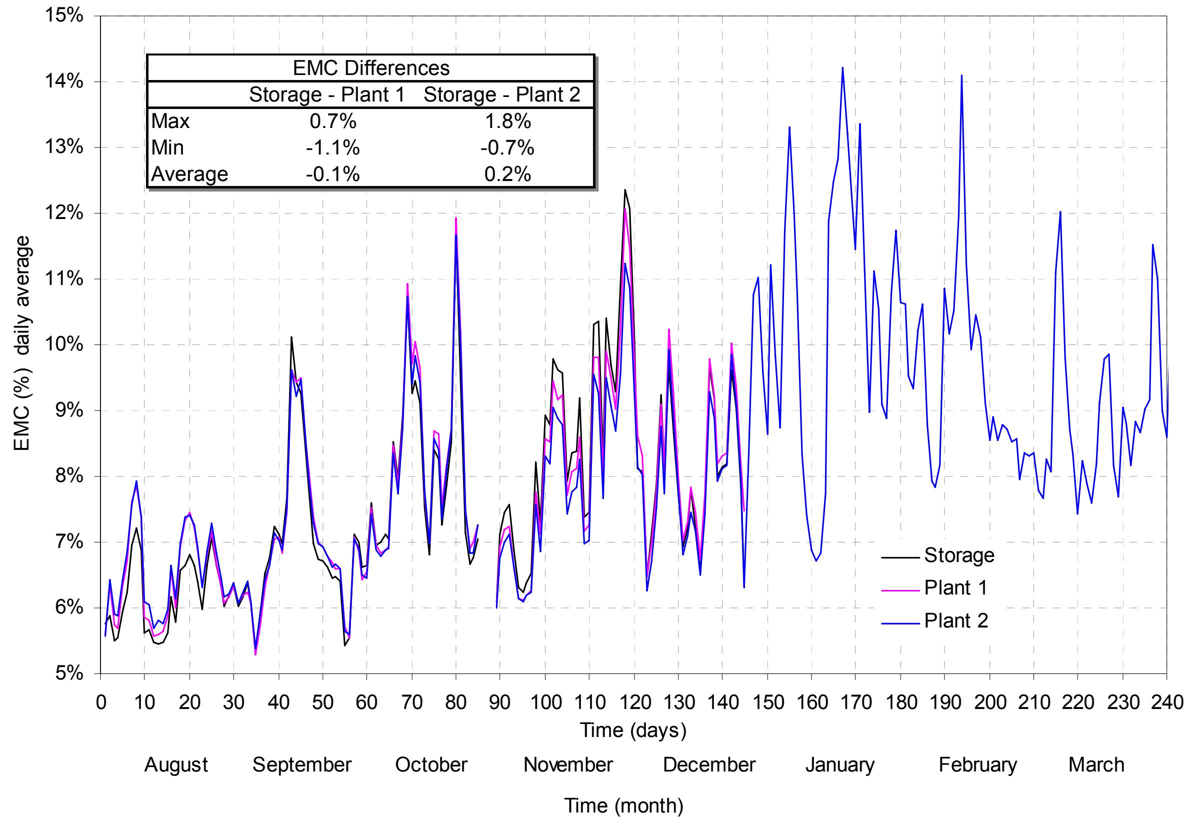


Figure 4-8. EMC during storage and processing in Cochabamba (August-March).

Figure 4-9 shows the average monthly equilibrium moisture content for the eight months of the study. EMC increases steadily with time during the first six months of the study, and then starts to decline from February (approximately 4.0% average increase from August to January). This corresponds to the natural changes in temperature and humidity that occur in the outdoor weather.

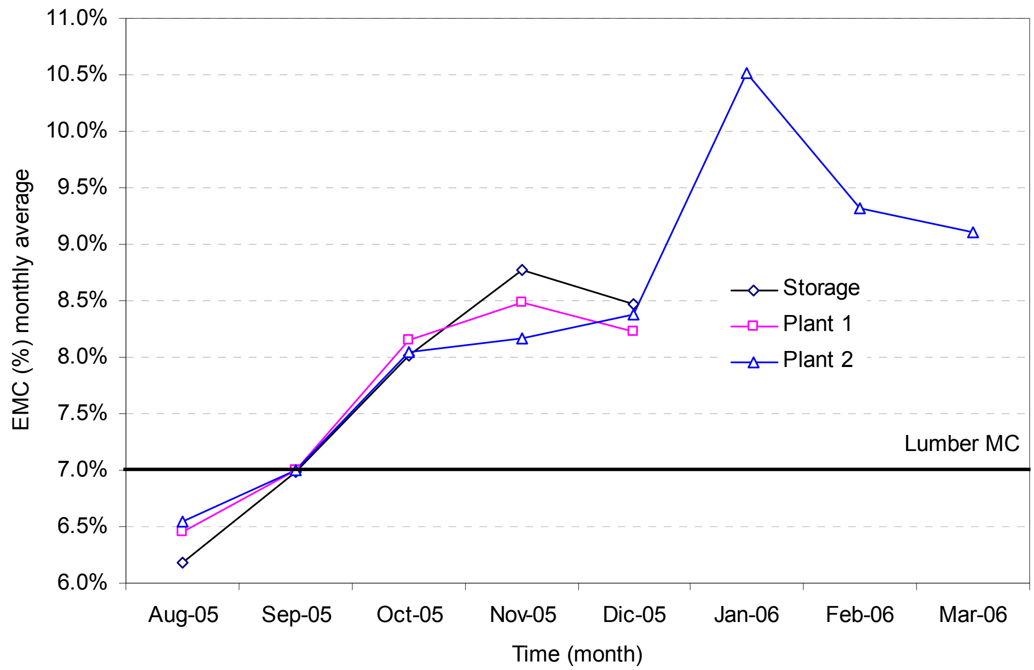


Figure 4-9. Monthly average EMC in Cochabamba (August'05-March'06).

This company manufactures solid wood doors and dries its lumber to a target moisture content of 7%, as confirmed during the on-site evaluations discussed in the previous chapter. Thus, during the months of the research, there is a potential moisture gain in the order of 1.0 to 3.5 %, due to a difference between initial moisture content and EMC. The exact amount and distribution of the moisture content will depend mainly on time spent in storage and manufacturing, species, thickness, stacking method and initial MC distribution after drying.

La Paz

Temperature and relative humidity was measured from late October to March in a flooring and furniture parts manufacturing plant in La Paz, Bolivia. Daily averages of equilibrium moisture content were calculated from these readings and are shown in Figure 4-10. The embedded table shows a summary of the differences between the storage and the two plant locations. Missing data in the storage curve during days 51 to 58 correspond to the partial retrieval of data during these days. EMC scale starts at 5% to emphasize the differences.

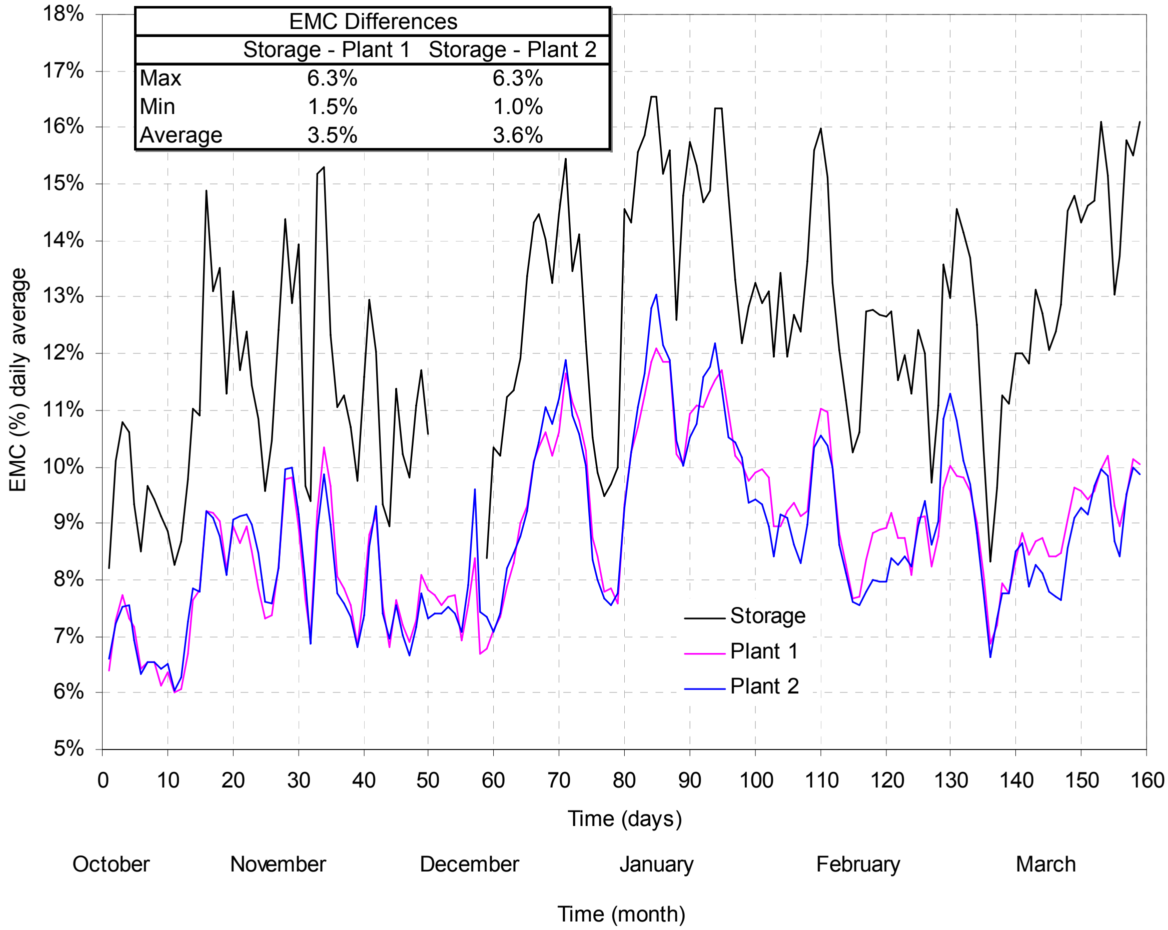


Figure 4-10. EMC during storage and processing in La Paz (October'05-March'06).

A marked difference between the storage and the manufacturing area is evident in the chart, with average differences between storage and processing plant of about 3.5%. This can be explained by the different designs of the storage and manufacturing area: the storage area in this company consists of a covered shed opened at its four sides, and its manufacturing area is a closed shed heated during winter months (heating was not working during the study). The difference between storage and plant conditions can be better appreciated looking at EMC monthly averages in Figure 4-11.

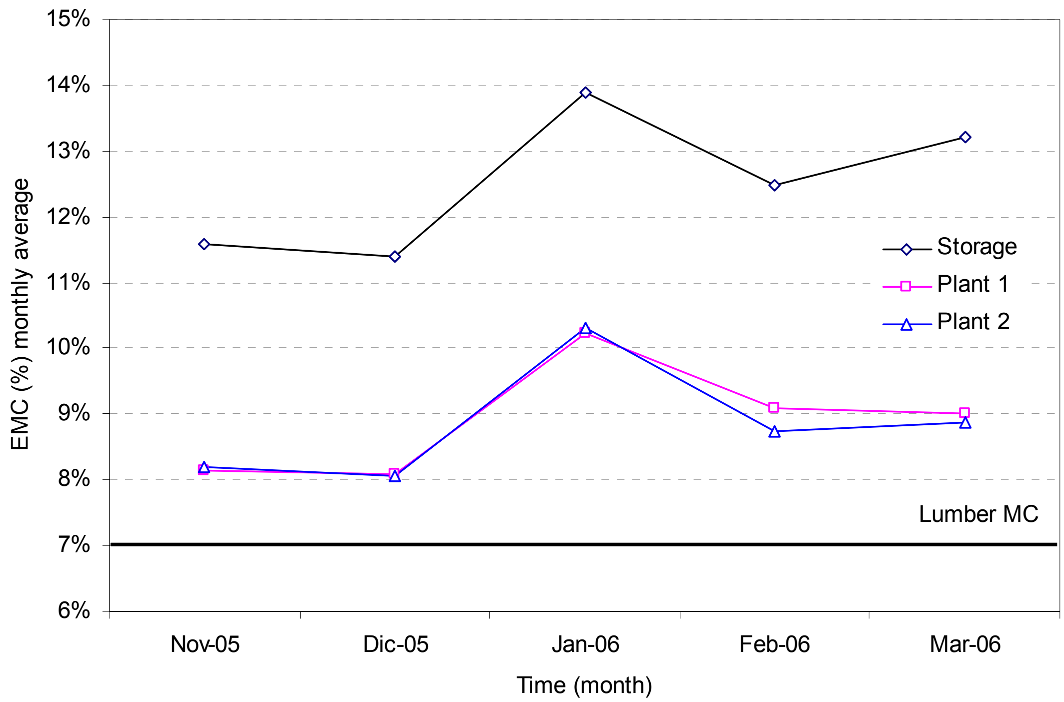


Figure 4-11. Monthly average EMC in La Paz (November'05-March'06).

A growing trend in EMC is apparent during the months of the study. This company dries lumber for furniture parts to a 7% moisture content, as observed during the on-site evaluations. Thus, lumber is exposed to a difference between moisture content and EMC of about 4.5% (December) to 7% (January) in storage and from 1 to 3% inside the manufacturing plant. Furniture parts are usually of relatively small thicknesses, increasing the risk of dimensional changes and gluing problems.

Results in this plant suggest the need to use a closed environment for storage of dry lumber; this will help to reduce the differences with the manufacturing facility and also relatively high EMC during the rain season.

<u>Santa Cruz</u>

Temperature and relative humidity was measured from late October 2005 to March 2006 in a millwork and garden furniture manufacturing plant in Santa Cruz. Daily averages of the calculated equilibrium moisture content are shown in Figure 4-12. The table shows a summary of the differences between the storage and the two plant locations. Missing data in the storage curve during days 52 to 56 correspond to the partial retrieval of data during these days. EMC scale in the graph starts at 5%.

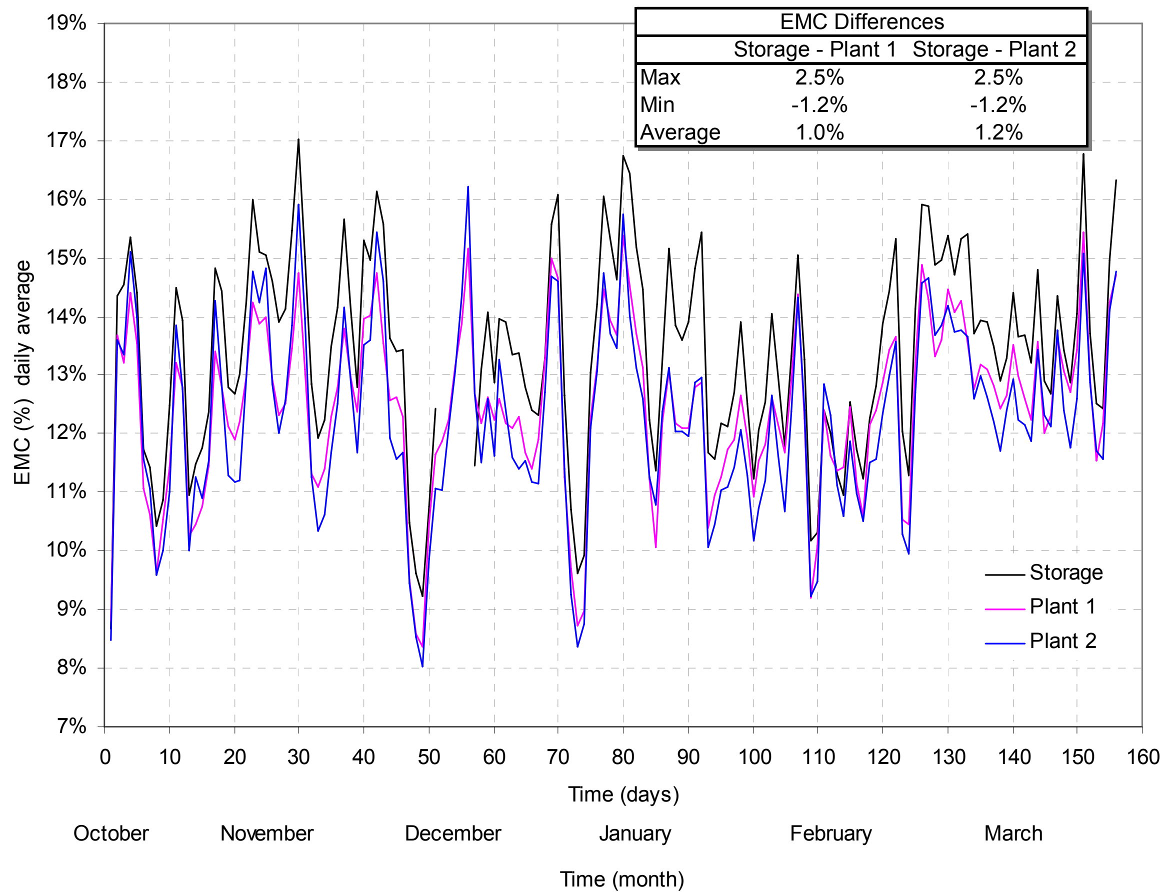


Figure 4-12. EMC during storage and processing in Santa Cruz (October'05-March'06).

Figure 4-12 shows a difference between storage and the two plant curves of about 1%. Both storage and manufacturing plant use a three-walled shed configuration but due to the presence of machinery and personnel temperature is higher (1.5°F higher in average, according to the results of the study) inside the plant, which decreases EMC.

Figure 4-13 shows monthly averages of equilibrium moisture content. There is a sharp increase in March, due to a much higher rain precipitation during this month (110.6mm in February and 226.5mm in March, according to the National Service of Meteorology and Hydrology of Bolivia, 2006). A difference between the two locations inside the plant is noticeable, a probable explanation is that Plant 1 corresponds to the finishing sector, where products are sanded by hand and operators constantly spray the floor with water to improve working conditions (average temperature during these months was 81ºF, with peaks of 90ºF early in the afternoon, according to the results of the study).

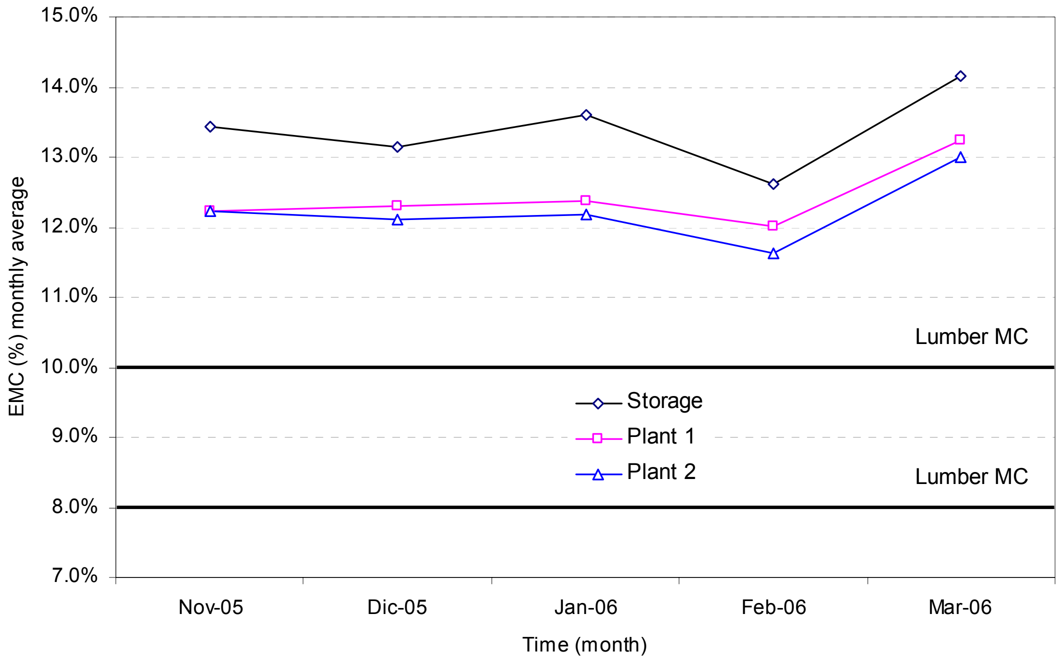


Figure 4-13. Monthly average EMC in Santa Cruz (November'05-March'06).

This company dries lumber to 8% and 10% MC for millwork and garden furniture, respectively. Therefore, during the months of the study, there is a difference between EMC and initial lumber's MC of approximately 3% to 6%. Results suggests the need for a better control of storage and plant conditions during these months, by closing the storage area and, if possible, installing a heating system to decrease the EMC (Simpson, 1991). The company needs also to improve air circulation inside the manufacturing plant.

<u>Summary of storage and plant studies</u>

Average EMC in storage and plant facilities in Cochabamba varied from a minimum of 6% in August to 10.5% in January. An upward trend in EMC is evident during these months.

Conditions in storage and plant can be considered equivalent, since EMC differences were of 0.2% in average, due to the similarity of facilities design.

Differences between EMC in storage and processing plant in La Paz was the greatest of the three locations, 3.5% in average, chiefly due to an open shed configuration for storage and a closed environment for the plant. EMC ranged from 9.6% in October to 13.9% in January for the storage area and from 6.9% to 10.2% in the processing plant. A clear upward trend in EMC was also identified during the five months of the study.

During October and March, no clear increasing trend was found in the data of EMC for the plant in Santa Cruz. Average Equilibrium moisture content ranged from 12.6% in February to 14.1% in March for the storage area and from 11.6% to 13% inside the manufacturing plant. EMC in storage area was in average 1.0% higher than that in the plant.

Companies of the study dry lumber to a moisture content of 7-8%, which suggests that lumber stored or processed during the months of the research can potentially gain moisture, being this gain higher in Santa Cruz and La Paz. Results show a need to improve storage environment control in all cases, but particularly important in companies located in La Paz and Santa Cruz, which should at least turn their storage area into a closed shed. It is also recommended to improve climate control inside the manufacturing plant in Santa Cruz.

Shipping Studies

This section will address the evaluation of EMC changes during shipping of wood products from two cities in Bolivia en route to ports in the United States. The purpose was to identify differences between EMC and wood moisture content, differences between container environment and inside packages, and possible trends of changing EMC during the time of the studies.

Cochabamba – Miami (first shipment)

Two data loggers were installed in shipment of solid wood doors from Cochabamba to Miami. The species used was was Mara Macho (*Cedreling cateneaformis*). The shipment was loaded on a truck and departed on July 31st, 2005 and arrived in Miami on September 5th, 2005. The frequency of the measurements on the data logger was one reading every 30 minutes. The maximum, minimum and average values for temperature, relative humidity and the calculated equilibrium moisture content are shown in Table 4-3.

Table 4-3. Temperature, relative humidity and EMC conditions during first shipping from Cochabamba, Bolivia to Miami, U.S., measured in the shipping container and inside a package of goods.

Measurement	Min	Max	Average
INSIDE PACKAGE			
Temp (oF)	43.9	97.0	72.5
RH (%)	25.8	73.6	55.6
EMC (%)	5.4%	14.0%	10.1%
OUTSIDE PACKAGE			
Temp (oF)	33.3	97.8	72.7
RH (%)	23.4	67.8	52.3
EMC (%)	5.0%	12.4%	9.6%

The maximum temperatures occurred when passing the equator and the lowest ones while passing the frontier between Bolivia and Chile, which is located in the Andean mountains at more than 15,300 feet above sea level and where freezing temperatures are common. Hour-by-hour results for the two data loggers are shown in Figure 4-14.

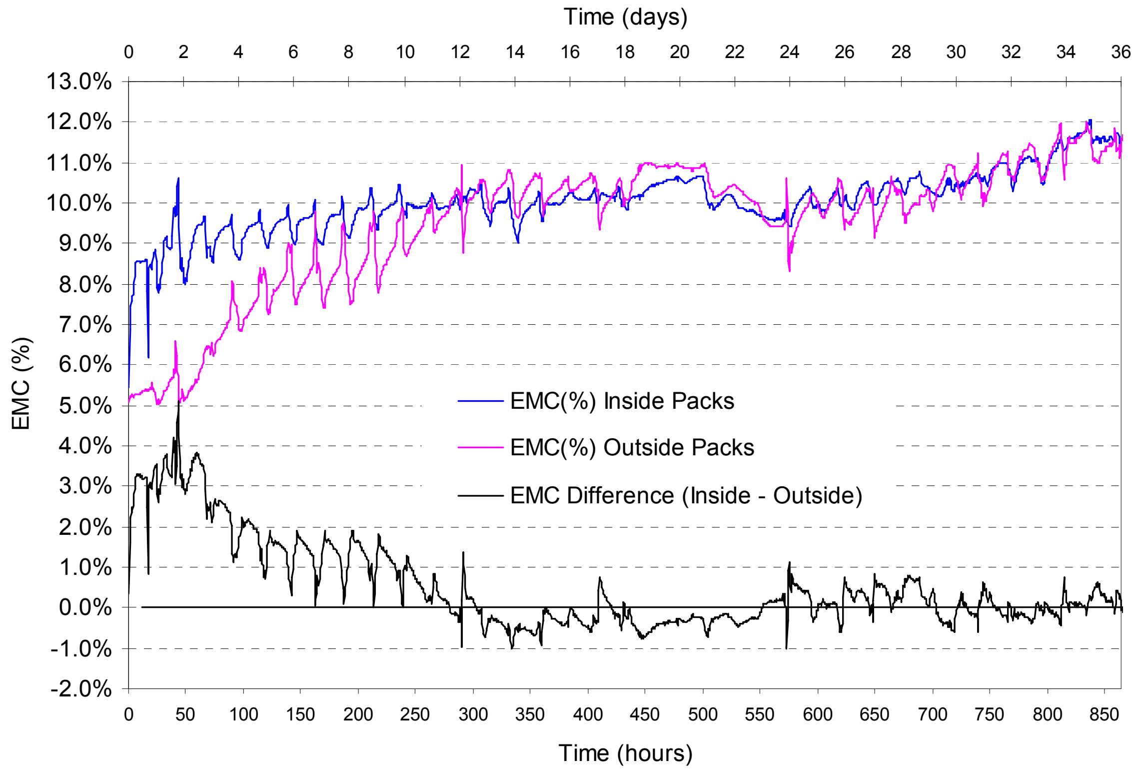


Figure 4-14. EMC during first shipping Cochabamba -Miami.

Several remarks can be made from the results shown in the previous figure:

- Until the 12th day there is a marked difference between the equilibrium moisture content inside and outside the packages, and from there on, conditions even out, as can be seen in the curve for EMC differences (a maximum difference of 5.1% in the 43th hour, corresponding with the passing the Bolivian-Chilean frontier; then from the 12th day difference it is not higher than 1%). The initial difference between conditions inside and outside the unit loads can be explained by the packaging material, especially stretch plastic wrap, providing a barrier against ambient moisture for approximately 12 days, after which moisture inside packs equals that of the container environment. Another reason could be residual surface moisture in the products that took some time to evaporate and escape from the package.
- Variations of EMC during the same day are less marked inside the packages, with the

curve showing less sharp changes during one day. Apparently the packaging has a "shield" effect against extremes of temperature and humidity, which can also help to avoid condensation (Knobbout, 1972).

- If wood is shipped with an initial moisture content of 7%, it will be exposed to a relatively high EMC (a mean of about 10%, increasing to 12% approaching its destination) during a relatively long period of time, which, according to previous research (Forest Products Laboratories Division, 1952; Zhang, 2005 and USDA, 1978) can lead to significant moisture gains in wood products, especially in pieces located in the exterior faces of the packages.

Cochabamba – Miami (second shipment)

A second shipment of doors and moldings from Cochabamba to Miami was monitored during January-February of 2006. Table 4-4 shows the main statistics for temperature, relative humidity and equilibrium moisture content.

Table 4-4. Temperature, relative humidity and EMC conditions during second shipping from Cochabamba, Bolivia to Miami, U.S., measured in the shipping container and inside a package of goods.

Measurement	Min	Max	Average
INSIDE PACKAGE			
Temp (ºF)	64.9	81.5	76.1
RH (%)	45.2	66.4	60.7
EMC (%)	8.5%	12.1%	11.0%
OUTSIDE PACKAGE			
Temp (ºF)	47.5	84.4	75.4
RH (%)	46.7	46.7	64.2
EMC (%)	8.7%	13.1%	11.7%

Figure 4-15 shows the hourly values for EMC and the difference between conditions inside and outside the packages.

Average values for EMC were higher than those of the previous shipment (Table 4-3), probably due to the humid season. Initial conditions during the first shipment, that took place during dry season (July-August) were as low as 5% EMC (Figure 4-14), compared with those in Figure 4-15, where initial EMC values were higher than 9%.

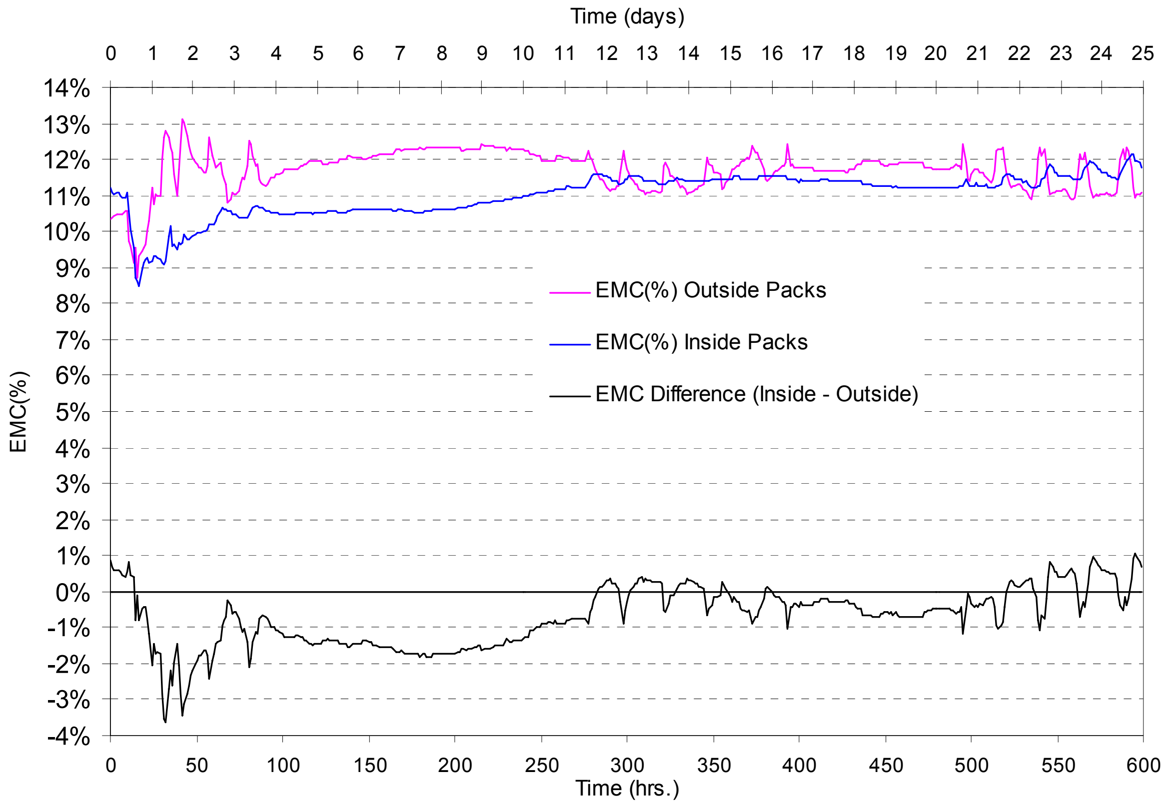


Figure 4-15. EMC during second shipping Cochabamba -Miami.

Overall, conditions outside and inside package showed less marked changes than the first shipping study; being a probable reason that this time the package was placed further from the container walls. Also, climate inside the package showed less sharp changes of temperature and relative humidity than in the container environment. Products in this shipment were completely wrapped with stretch-plastic, including the top and bottom, which may have contributed to a smoother EMC curve, confirming that plastic-wrapping provides protection against sharp changes in climate conditions. As in the first shipping study, conditions inside and outside the packs start to even out from the 12th day.

La Paz – Norfolk

This shipment consisted of furniture parts. Departure date from Arica was December 8th and the container arrived to Norfolk, Virginia on January 3rd; and from there was transported by ground to Michigan and delivered on January 19th. The packaging materials used in this case were similar as in the previous studies, and the stretch plastic-wrap covered also the top and bottom of the packages. Although two data loggers were installed, the sensor outside the packages stopped working before departure due to an unknown reason, thus only readings from inside the packs were taken. Table 4-5 lists the statistics for temperature, relative humidity and calculated equilibrium moisture content.

Table 4-5. Temperature, relative humidity and EMC conditions during first shipping from La Paz, Bolivia to Norfolk, U.S., measured in the shipping container.

INSIDE PACKAGE*			
Measurement	Min	Max	Average
Temp (oF)	47.5	80.8	71.4
RH (%)	45.3	67.7	59.9
EMC (%)	8.6%	12.3%	10.9%

* All measurements up to the 29th day

Figure 4-16 shows the curve with EMC values. The dashed line represents the arrival of the container to Norfolk, Virginia and then its ground transportation to Michigan.

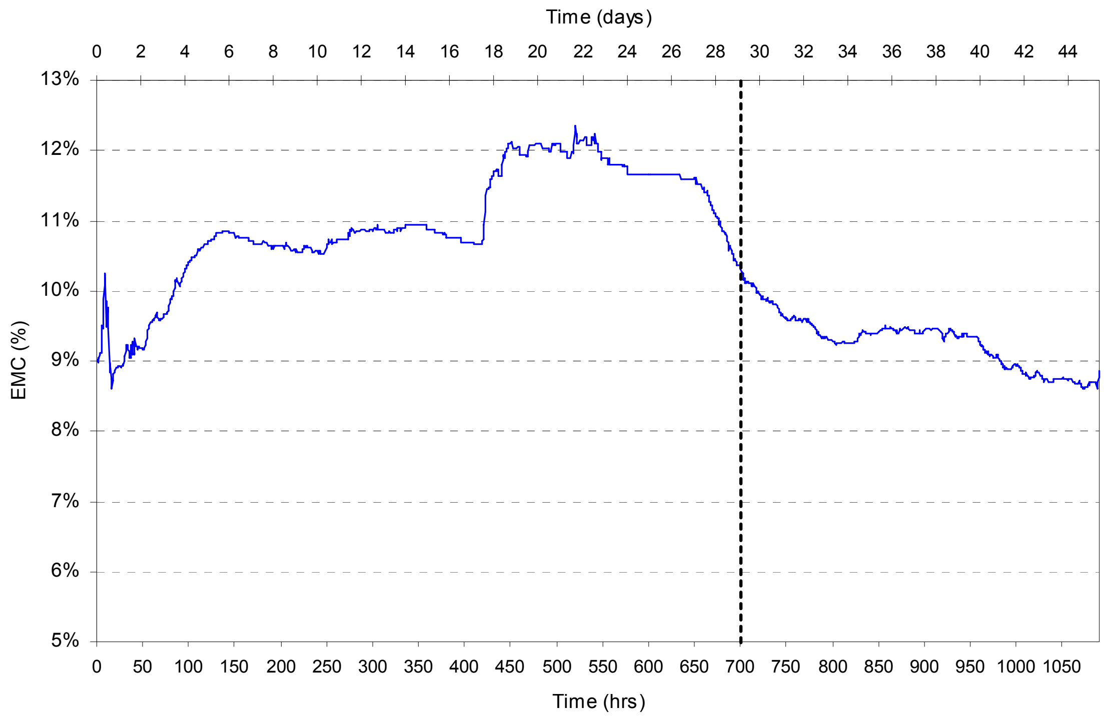


Figure 4-16. EMC during shipping La PazNorfolk.

It can be noticed that changes in EMC are more gradual as in the second study. As explained before, this due to a complete plastic-wrapping of the packages, that attenuates sharp drops and peaks of temperature and relative humidity.

This company dries lumber to a moisture content of 7%, and average EMC during shipping was of 3.9% above initial MC and almost 5% above during days 18 through 28, with the potential moisture gain in the products.

<u>Summary of Shipping Studies</u>

Sample size for the shipping studies (number of companies) was small and routes limited only to two Bolivian cities and two U.S. destinations, thus the conclusions listed here can not be generalized.

Average difference between the EMC inside packages and the nominal wood moisture was of 3% and 4% for the first and second shipments from Cochabamba to Miami, respectively; and 3.9% for the shipment from La Paz to Norfolk. These figures indicate a potential for moisture pickup, especially among the pieces located in the exposed sides of the packs.

The shipping route did not have a large influence in average EMC inside packages during the shipments, having values of 10.1%, 11.0 %, 10.9% for Cochabamba-Miami (first and second) and La Paz-Norfolk, respectively.

Packaging method was determined to have an influence in the climate inside the packages. The practice of enclosing products entirely with stretch-wrap provides a protection against sharp changes in temperature and relative humidity. Packaging however, does not appear to prevent the products to eventually reaching the same average conditions as the container environment after a lag of approximately 12 days. Difference between EMC averages inside and outside packages ranged from were 0.5% and 0.7%.

Dimensional changes caused by changes in moisture content

Once wood is dried below 15%, most problems with moisture content of wood are related to dimensional changes (Eckelman, 1998). Although rate of adsorption depends on various factors – thickness, short- or long-term weather changes and species among others - and usually occurs as a gradient in the cross section, dimensional changes can be estimated using the following equation (Forest Products Service, 1978):

$$\Delta D = \frac{(M_F - M_0) \times D}{(\frac{100}{S_T} - 1) \times FSP + M_0}$$

Where M_F = final moisture content Equation [4-2]

M_0 = initial moisture content

D = initialdimension

S_T = tangential (or radial) shrinkage

FSP = fiber saturation point

Equation 4-2 was used to estimate dimensional changes in the tangential direction (dimensional changes in the radial direction can be estimated as half of tangential values).

Four Bolivian woods, six common dimensions and a moisture content changes from 1 to 7% were included. Results of these computations are shown in Figure 4-17.

Is evident that even small changes in moisture content can create problems, especially in assembled products (entry doors, cabinet doors, furniture and frames) and solid flooring (strip and plank). As an example, for dense North American hardwoods, such as red or white oak (with tangential shrinkage between those of Cambara and Soto), a 2% difference in EMC can lead to splits and cracks in the end-grain (Wengert, 1988)

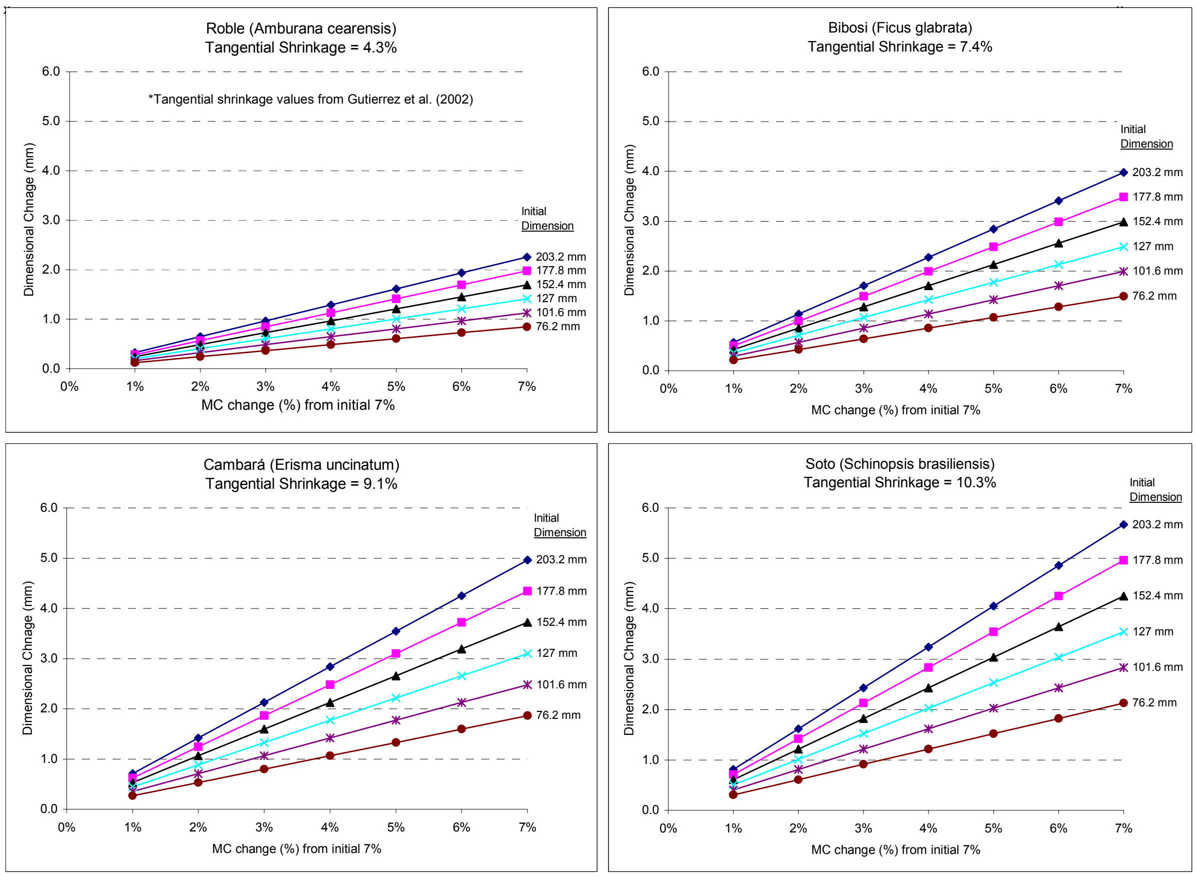
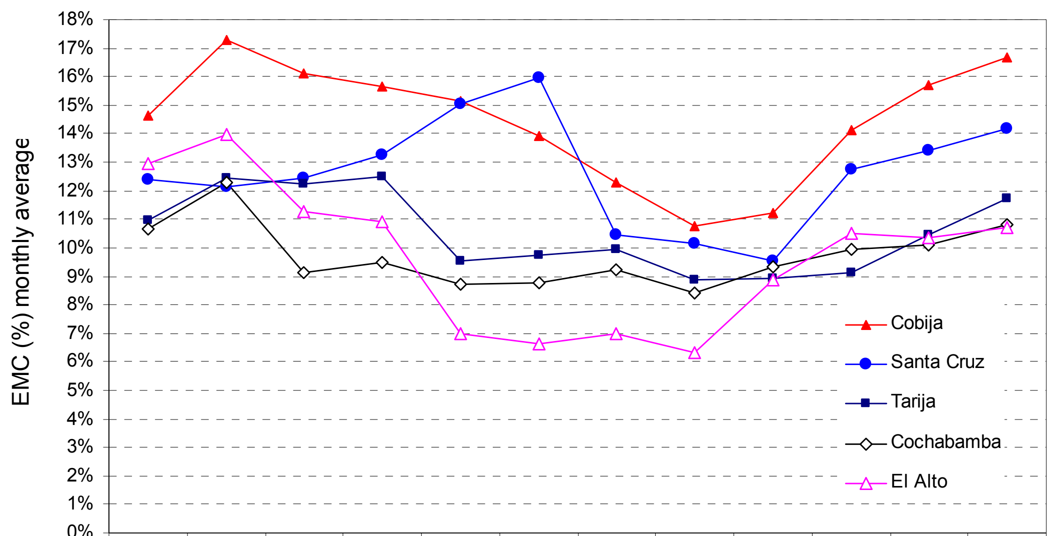


Figure 4-17. Dimensional changes as function of MC change and species.

Equilibrium Moisture Content in 11 Bolivian Locations

The potential for lumber gain or loss of moisture is a function of the average equilibrium moisture content (Forest Service, 1978). In order to provide with a reference for the industry, historic temperature and relative humidity data (from the National Service of Meteorology and Hydrology of Bolivia, 2006) was used to calculate the equilibrium moisture content in eleven cities of Bolivia. Results are shown in Figure 4-18. Knowing these values is essential to control moisture change during dry-lumber storage. The three main geographical regions are evident by looking at the values of EMC ranges (maximum minus minimum EMC values throughout the year):



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cobija	14.7%	17.3%	16.1%	15.6%	15.1%	13.9%	12.3%	10.8%	11.2%	14.1%	15.7%	16.7%
Santa Cruz	12.4%	12.2%	12.4%	13.3%	15.1%	16.0%	10.4%	10.2%	9.6%	12.7%	13.4%	14.2%
Tarija	11.0%	12.5%	12.2%	12.5%	9.5%	9.7%	9.9%	8.9%	8.9%	9.1%	10.4%	11.7%
Cochabamba	10.7%	12.3%	9.1%	9.5%	8.7%	8.8%	9.2%	8.4%	9.3%	10.0%	10.1%	10.8%
El Alto	13.0%	14.0%	11.3%	10.9%	7.0%	6.6%	7.0%	6.3%	8.9%	10.5%	10.3%	10.7%
Guayaramerin	15.4%	16.7%	15.8%	15.1%	14.8%	13.1%	11.6%	10.4%	11.2%	12.6%	14.7%	16.1%
Trinidad	13.8%	14.4%	13.9%	13.2%	14.2%	13.7%	11.7%	10.5%	10.0%	12.9%	14.2%	15.4%
La Paz	12.2%	13.9%	10.1%	9.6%	10.6%	6.9%	8.2%	6.1%	9.8%	7.2%	7.7%	9.1%
Oruro	10.5%	10.7%	9.1%	9.1%	7.1%	7.3%	6.8%	6.6%	8.4%	8.0%	8.3%	8.5%
Potosi	13.0%	16.1%	11.8%	11.3%	8.2%	7.8%	7.6%	7.6%	8.5%	9.2%	10.5%	12.3%
Sucre	12.6%	15.0%	12.4%	12.8%	8.4%	8.2%	9.6%	8.6%	11.4%	13.1%	11.9%	12.4%

Source: Temperature and Relative Humidity data from the National Meteorology and Hydrology Service (SENAMHI)

Figure 4-18. Monthly averages of outdoor equilibrium moisture content in 11 Bolivian cities.

The eastern side of the country (Santa Cruz, Trinidad, Cobija, Guayaramerin), distinguished by low altitude (777 to 1,347 feet above sea level)and tropical weather with EMC's ranging from 17.3% in the rain season to 9.6% during winter months. Variation between seasons is relatively high in this region (as expressed by EMC ranges, from 5.4% in Trinidad to 6.5% in Cobija).

The valleys or central region, where the cities of Cochabamba, Sucre and Tarija are located at medium altitudes (6,300 to 9,147 feet above sea level), and have a temperate weather. EMC in this region ranges from 8.2% to 15%, and has the lowest EMC variation between seasons (EMC ranges of 3.6% for Tarija and 6.8% for Sucre).

The western side of the country, where cities of La Paz, El Alto, Oruro and Potosi are located at high altitudes (12,000 to 13,400 feet above sea level) and with a rather cold weather. EMC's in this region range from 6.1% during winter and 16.1% during humid months. This region presents the highest variation between seasons, with EMC ranges from 4% in Oruro to 8.5% in Potosi.

EMC during Production Stages – Example

The data recorded in the study can be used to provide and example of how EMC may change during the different stages of production, and the potential moisture content change. Figure 4-19 shows a hypothetical situation with the different EMC conditions during stages of the production process for the company in La Paz. For simplicity, all steps where assumed to take place in consecutive months since December and variations between and within days are not taken into account for the analysis.

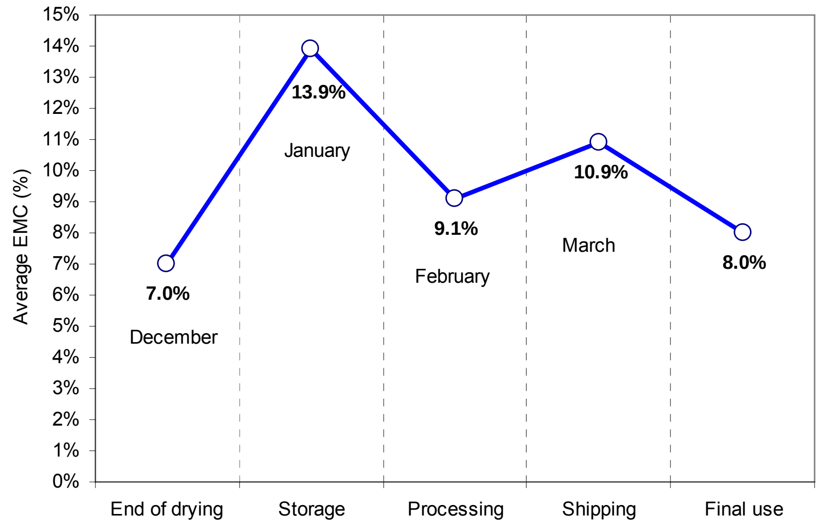


Figure 4-19. Example of EMC through production stages for company in La Paz..

In the example, the company dries its lumber to a 7% moisture content, then stores it an open shed, where in January the average equilibrium moisture content is 13.9%. Then lumber is processed inside the manufacturing plant, which climate conditions during February result in and average EMC of 9.1%. Once products are ready, they are prepared and shipped in a container to Norfolk. The container takes about a month to reach its destination port, and the average EMC is 10.3%. An intermediate storage in the brokers' warehouse is not considered in the example, but assuming the product reaches the final client directly, it will be exposed to an indoor equilibrium moisture content of usually 8% (Forest Products Laboratory, 1973).

These changes in EMC can lead to changes in moisture content in lumber or wood products, which in turn may cause dimensional changes. Assembled products, like doors and furniture can experience open joints, cracked panels, gluing and finishing problems and warp (Eckelman, 1998). In products like furniture parts and flooring, these MC changes can lead to problems like cup and gaps during flooring installation, or gluing and finishing problems when assembling parts into final products at destination. Decorative panels, balustrades and mantels, which usually have carved and turned surfaces can develop checks, mainly due to a moisture gradient. Other products that are usually dried to relatively high moisture content or not dried at all, like decking, posts and construction lumber may check and warp.

CONCLUSIONS

Temperature and relative humidity was recorded during several months in three Bolivian wood manufacturing plants and in three containerized ocean shipments of wood products to the U.S. Readings were then used to estimate the equilibrium moisture content.

Results of the studies show that significant differences exist between EMC conditions in storage, manufacturing and shipping in the companies where measurements were taken, and confirmed a potential moisture content change in lumber and end products.

Results from storage and plant studies showed important differences between equilibrium moisture content and lumber moisture content during post-drying stages. Depending on the geographical region and month of the study, difference between lumber MC and monthly average EMC were found to be from -1% to 7%, the biggest differences were found in La Paz and Santa Cruz. Difference between storage and processing EMC ranged from no difference to more than 3.6%, depending mainly on facilities design and region.

The results from storage and plant studies suggest the need to have a better control of dry-lumber storage and manufacturing facilities. If heating is not feasible, storage areas should at least be changed to a closed-shed facility with a design that facilitates the interior for reaching temperatures above outside climate in order to reach an EMC within plus or minus 2% of the moisture content of the lumber.

Regarding shipping studies, differences between lumber MC and average EMC during ocean-transport ranged from 3 to 4%. Origin and season of the study did not appear to have a significant influence on average transport EMC, with only a 1% difference between shipments in different seasons of the year. The packaging of products showed to have an influence in attenuating sharp changes of temperature and relative humidity inside the container, therefore reducing the risk of condensation. However, packaging materials did not prevent the interior of the unit loads to eventually reach the same average climate conditions as the container environment. Better results were attained when plastic-wrap totally enclosed the bundles of products. Conditions inside the packs also depended on location in the container.

Results from the shipping studies suggest that is a good practice to wrap wood products with stretch-wrap to avoid extreme conditions and condensation inside the packages. Also, whenever possible, packages should be placed away from the container walls.

In all cases, values of average EMC during storage, manufacturing and shipping were different than the moisture content of lumber after kiln-drying. The highest EMC's were recorded in open shed configurations and during shipping when the vessel is close to the Equator.

The following limitations of the study can be mentioned:

- Equilibrium moisture content was estimated using the equation derived from the Hailwood-Horrobin model (Hailwood and Horrobin, 1946) and coefficients by Simpson (1973). While this approach provides a good estimation, equilibrium moisture content actually varies with species (Ahmet et al., 2000 and Siau, 1995).
- The time span of the study was shorter than one year, and readings were taken mostly during the raining season, reducing the applicability of the data to these months.
- The study did not include the conditions of storage in the warehouse at destination, and if located in regions of intense weather (i.e., Florida or Arizona) this may negatively impact the product. Close communication with the client is needed to address this matter.
- Considering that most of kiln-dry lumber in Bolivia is processed and shipped as end-products, a more precise determination of moisture gains and distributions would require individual studies for every product category and location.
- The small samples size of the studies, limit the usefulness of the results. Companies may, however, conduct similar studies for their particular routes and packaging methods.

Based on the limitations of this work, future research could be conducted to determine moisture change and distribution, using the oven-dry method, weighting wood samples at every step of the production process, including the broker’s warehouse at destination. The studies could start with the most commonly processed species, thicknesses and products. Routes for the shipping studies should be selected among the most used ones by Bolivian companies. This methodology will allow researches to investigate more variables, like location inside the container and packages.

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APPENDIX A QUESTIONNAIRE

QUESTIONNAIRE

1 Name of the company ____________________

2 Name and position of contact ____________________

3 Location ____________________

4 Main product/activity ____________________

5 Number, type, brand, age and capacity of kilns

Number	Type	Brand	Country of origin	Age (years)	Capacity 2" basis (p^2)	Maximum temperature (ºC)
	☐ Steam heated ☐ Pre-dryer ☐ Direct fire ☐ Deshumidifier ☐ Solar	☐ Commercial dryer ☐ Locally made Brand: ______				
	☐ Steam heated ☐ Pre-dryer ☐ Direct fire ☐ Deshumidifier ☐ Solar	☐ Commercial dryer ☐ Locally made Brand: ______				
	☐ Steam heated ☐ Pre-dryer ☐ Direct fire ☐ Deshumidifier ☐ Solar	☐ Commercial dryer ☐ Locally made Brand: ______				
	☐ Steam heated ☐ Pre-dryer ☐ Direct fire ☐ Deshumidifier ☐ Solar	☐ Commercial dryer ☐ Locally made Brand: ______				
	☐ Steam heated ☐ Pre-dryer ☐ Direct fire ☐ Deshumidifier ☐ Solar	☐ Commercial dryer ☐ Locally made Brand: ______				
	☐ Steam heated ☐ Pre-dryer ☐ Direct fire ☐ Deshumidifier ☐ Solar	☐ Commercial dryer ☐ Locally made Brand: ______				

6 Volume, species and thicknesses usually dried

Species	Volume of lumber dried (in p^2)		Thicknesses
		☐ per month ☐ per year	☐ 1" ☐ 3" ☐ 1.5" ☐ Other ☐ 2" ____
		☐ per month ☐ per year	☐ 1" ☐ 3" ☐ 1.5" ☐ Other ☐ 2" ____
		☐ per month ☐ per year	☐ 1" ☐ 3" ☐ 1.5" ☐ Other ☐ 2" ____
		☐ per month ☐ per year	☐ 1" ☐ 3" ☐ 1.5" ☐ Other ☐ 2" ____
		☐ per month ☐ per year	☐ 1" ☐ 3" ☐ 1.5" ☐ Other ☐ 2" ____
		☐ per month ☐ per year	☐ 1" ☐ 3" ☐ 1.5" ☐ Other ☐ 2" ____
		☐ per month ☐ per year	☐ 1" ☐ 3" ☐ 1.5" ☐ Other ☐ 2" ____
		☐ per month ☐ per year	☐ 1" ☐ 3" ☐ 1.5" ☐ Other ☐ 2" ____

7. Drying control

- ☐ Based on Moisture Content
  - ☐ Moisture content determined by weight (sample boards)
  - ☐ Moisture content determined by probes or electric mositure meter
- ☐ Based on Time
- ☐ Other ______________________________

8. Moisture content of wood before drying

Proportion of material that comes green-off-the-saw ☐ %

Proportion of material that comes air-dried ☐ %

9. Energy source

- ☐ Natural gas
- ☐ Wood residues
- ☐ Other ______________________________

10. Are the following steps included in your drying process?

- ☐ Equalization
- ☐ Conditioning

11. Where do you obtain your drying schedules?

- ☐ Developed in the company
- ☐ Kiln manufacturer
- ☐ Other companiess
- ☐ Published materials
- ☐ Other ______________________________

12. Please, add any aditional comments about your drying operation or information that you think could be useful

____

____

____

____

APPENDIX B EVALUATION CHECKLIST

GENERAL INFORMATION

Company ______________________ Date (dd/mm/yy) __________

Location ______________________

Contact(s) ______________________

Main Product/Activity ______________________

KILN INFORMATION

Brand/Homemade ______________ Origin ______________

Capacity ______________ bd.ft. Age of kiln (years) __________

Type of Construction
- ☐ Aluminum panels
- ☐ Brick / concrete
- ☐ Wood construction

Energy Source
- ☐ Natural gas
- ☐ Wood waste
- ☐ Other __________

Control
- ☐ Manual
- ☐ Semi-automatic
- ☐ Automatic

Loading
- ☐ Track-loaded
- ☐ Package-loaded

A. KILN CONDITION AND MANTEINANCE

A1 Maintenance is done according to a program?
- ☐ Manteinance is done according to a schedule/plan
- ☐ No. Repairs and maintenance are done when problems occur

A2 Are manteinance works and repairs recorded?
- ☐ Manteinance works are recorded regurarlly
- ☐ No manteinance records are kept

A3 Are there noticeable leaks in doors, walls and roof?
- ☐ No visible leaks
- ☐ Small leaks visible
- ☐ Large leaks are visible

A4 Condensation (check inside kiln)
- ☐ No or slight evidence of condensation
- ☐ Corrosion problems due to condensation or leaks
- ☐ Severe damage due to condensation or water

A5 Type of wet and dry bulb thermometers
- ☐ RTD
- ☐ Thermocouple
- ☐ Glass-stemmed (liquid expansion)
- ☐ Bi-metalic (differential expansion)

A6 Number of thermometers
- ☐ Dry-bulb thermometers
- ☐ Wet-bulb thermometers/EMC waffers

A7 Location of dry-bulb thermometers
- ☐ Sensors too close to heat sources
- ☐ Dry-bulb thermometer below wet-bulb
- ☐ Sensor too close to walls or load of lumber
- ☐ Location of sensor not checked

A8 Frequency of wet-bulb wick change
- ☐ Wick changed for every charge
- ☐ Wick changed when is dirty or crusty
- ☐ Rarely changed or not changed at all
- ☐ Not applicable

A9 Frequency of EMC waffers change
- ☐ Changed for every load or according to manufacturer
- ☐ Only changed when problems occur
- ☐ Not changed since installation
- ☐ Not applicable

A10 Calibration checks of temperature sensors
- ☐ Calibration checks made every year or more often
- ☐ Calibration checks made only when problems occur
- ☐ Not calibrated since installation

A11 Air speed across the wet-bulb
- ☐ 300 fpm or greater
- ☐ Between 150 and 300 fpm
- ☐ Less than 150 fpm or no airflow

A12 Water flow to the wet-bulb wick
- ☐ Proper water flow and temperature to wet bulb wick
- ☐ Waterflow is too rapid or too slow
- ☐ The wet-bulb sensor touches the water in reservoir
- ☐ Water is unusually hot or cold
- ☐ Not aplicable (use EMC waffer)

A13 Steam heat valves operation

- ☐ None or barely detectable steam passes when valves close
- ☐ Steam passes noticeably when valves are closed
- ☐ Not aplicable

A14 Steam/water spray valve operati

- ☐ No steam/water passes when valves are closed
- ☐ Steam/water passes spray line when valves are closed
- ☐ Not aplcable

A15\ Steam traps location and installation

- ☐ Traps properly located (downstream from and below coils)
- ☐ Traps difficult to access for maintenance and repairs

- ☐ Heating coils individually trapped
- ☐ More than one tracer line is manifolded into a common trap

---

- ☐ Strainers properly placed upstream of traps
- ☐ No strainers installed

- ☐ Not aplicable

A16 Steam traps operation

- ☐ All traps are working properly
- ☐ Traps cannot handle condesate (undersized)
- ☐ One or more traps are not working
- ☐ Not aplicable

A17 Steam traps manteinance

- ☐ Manteinance of traps made annually or more often
- ☐ Ocasional manteinance of traps when problems occur
- ☐ Last maintenance of traps more than 2 years ago
- ☐ Not aplicable

A18 Type of fans system

- ☐ Variable speed ☐ External motors ☐ Line-shaft ☐ Propeller-type fans ☐ Reversible fans
- ☐ Fixed speed ☐ Internal motors ☐ Cross-shaft ☐ Disc fans ☐ Non-reversible fans

A19 Fan floor

- ☐ Fan floor extends to edge of lumber pile
- ☐ Fan floor does not extend to edge of lumber pile

- ☐ Fan floor can support manteinance personnel
- ☐ Fan floor not safe for manteinance

A20 Fan reversal

- ☐ Fan reversals occurred normally
- ☐ More than 75% of reverals occurred as scheduled
- ☐ Less than 75% of reversals occurred as scheduled
- ☐ Non-reversible fans

Fan reversal every ☐ hrs

A21 Conditions of fans

- ☐ Fans tight on shaft and no visible blade damage exist
- ☐ Fans not tight on shaft or blade damage evident
- ☐ Fans in noticeably poor conditions

A22 Air speed check (in feet per minute)

Package				← Upper Row
Bolster space				
Package				← Middle Row
Bolster space				
Package				← Lower Row

A23 Vents type

- ☐ Vents on roof ☐ Modulated vents ☐ Manually activated ☐ Normal vents
- ☐ Vents on sides ☐ On/Off vents ☐ Automatic control ☐ Powered vents

A24 Leakages around vents

- ☐ All Vents open to the same height, no noticeable leakage
- ☐ Slight leakage through vents when closed, no light seen
- ☐ Noticeable leakage through vents when closed

A25 Size and number of vents

	Estimated area of each vent (cm^2)
	Number of vents

A26 Type of heating system

- ☐ Steam
- ☐ Hot oil
- ☐ Hot water
- ☐ Direct fire
- ☐ Electric resistances

A27 Heating coils type

Type	Materials: Coils	Materials: Fins
☐ Plain	☐ Iron	☐ Iron
☐ Finned	☐ Aluminum	☐ Aluminum
	☐ Copper	☐ Copper

A28 Heating coils conditions

- ☐ Clean, no foreign materials
- ☐ Some dirt and rust
- ☐ Severly rusted, coils coated with foreign material

A29 Slope of heating coils

- ☐ Proper slope in the right direction
- ☐ Insufficient slope
- ☐ No slope or slope in the wrong direction

A30 Insulation of steam feedlines

- ☐ Steam feedlines properly insulated
- ☐ Insulation noticeably damaged
- ☐ Steam feedlines not insulated at all

A31 Leaks in fittings, steam pipe, and coils

- ☐ No visible leaks
- ☐ Small leaks
- ☐ Many medium or large leaks

A32 Humidification system type

- ☐ Steam spray
- ☐ Water spray
- ☐ Other ____________________

A33 Humidification system conditions

- ☐ Nozzles produce uniform steam
- ☐ Nozzles do not produce uniform steam or are blocked

A34 Drainage from kiln floor

- ☐ Good drainage, no liquid water inside kiln
- ☐ Poor drainage, liquid water on lumber or kiln floor

A35 Set points and kiln response

Time necessary to reach set points from start-up		hrs		
Time necessary to reach set points during operation		hrs		
Temperature (ºC)		Setpoint		Actual
Relative humidity (%)		Setpoint		Actual

B. STACKING PRACTICES

B1 Stickers type, size and material

- ☐ Plain-shaped
- ☐ Special profile
- ☐ Solid wood
- ☐ Plywood or eng. wood

Width ____________ mm

Depth ____________ mm

Lengths ____________ mm

B2 Species used for stickers and bolsters

____________________ ____________________

____________________ ____________________

____________________ ____________________

B3 Stickers moisture content (take 20 readings)

B4 Sticker thickness uniformity (measure 20,mm)

B5 Sticker straightness (check crook in 20)

- ☐ Very few or no stickers with significant crook (2" or more)
- ☐ Between 5 and 10 stickers with significant crook
- ☐ More than 10 stickers with significant crook

B6 Bolster thickness uniformity (check 20)

- ☐ Very uniform thickness of bolsters (range <1/8")
- ☐ Moderate variation in bolster thickness (range <3/8")
- ☐ Severe variation in bolster thickness (range >3/8")

B7 Sticker alignment (inspect 15 columns of stickers) write down how many are out of alignment

B8 Missing stickers (inspect 15 columns of stickers write down how many are missing)

B9 Size of packages and sticker spacing

Widht ☐ cm
Height ☐ cm
Length (s) ☐ m

Sticker spacing ☐ cm

B10 Stacking method

- ☐ End-trimmed lumber
- ☐ Box-piling
- ☐ Even-one-end
- ☐ Not even both ends

B11 Sides of packages

- ☐ Sides of packages are even
- ☐ Some courses not even
- ☐ Most courses not even

B12 Lumber thickness variation as seen in the ends of piles or packages

- ☐ No stickers bent due to lumber thickness variation
- ☐ Some boards do not touch stickers or stickers are bent
- ☐ Stacking is noticeably irregular due to lumber thicknes variation

B13 Bolster placement (inspect 15 bolsters)

- ☐ Bolsters perfectly aligned with stickers
- ☐ 3 or less out of alignment or missing
- ☐ More than 4 out of alignment or missing

B14 Plenum space (inspect a loaded kiln)

Number of sticker spaces	
Number of bolsters spaces	
Thickness of stickers (mm)	
Thickness of bolsters (mm)	
Actual plenum space (cm)	

B15 Baffle use

- ☐ Baffles flush against top, bottom and ends of load
- ☐ Some spaces smaller than 15cm between load and baffles
- ☐ Many open spaces greater than 30cm
- ☐ Baffles are not used

B16 Height of piles and baffle contact

- ☐ All piles of same height, uniform contact with top baffle
- ☐ Some variation in pile height
- ☐ Several piles do not make contact with baffles
- ☐ No baffles are used

B17 Package/pile placement in a drying load

- ☐ Packages properly placed, allow for good airflow
- ☐ Airflow non uniform due to load placement
- ☐ Packages poorly placed; causing airflow short circuits

C. PROCESS CONTROL

C1 Process control made by

- ☐ Moisture content (weight or probes)
- ☐ Time

C2 Number of sample boards/probes used per load

[   ] samples /probes per [   ] bf

C3 Selection of sample boards

- ☐ Samples are selected randomly from the load
- ☐ Samples represent most difficult and easiest drying lumber
- ☐ Other ____________________

C4 End coating of sample boards

- ☐ Sample boards are not end-coated
- ☐ Commerical product for end-coating is used
- ☐ Aluminum paint or tar-based paint is used
- ☐ Wood adhesive
- ☐ Not aplicable

C5 Length of sample boards

[   ] Length (cm)

C6 Sample boards placement in the load

- ☐ In pockets within the load
- ☐ In bolster spaces
- ☐ Sample boards not placed in the load
- ☐ Not aplicable

- ☐ Kiln samples located to represent different zones
- ☐ Samples located for convinience of handling
- ☐ Not aplicable

C7 Acces to sample boards

- ☐ Easy and safe access to sample boards
- ☐ Some dificulty in accessing sample boards
- ☐ Access to sample boards unsafe and very difficult
- ☐ Not aplicable

C8 Initial MC of sample boards determined by:

- ☐ Oven-dry method
- ☐ Probes or electric moisture meters
- ☐ Other ____________________

C9 Sample boards MC during drying determined by:

- ☐ Weight
- ☐ Probes or electric meters
- ☐ Other ____________________

C10 Correction factors for electric MC meters or probes

- ☐ Readings are corrected for species and temperature
- ☐ Readings are corrected for species
- ☐ No or wrong correction factors are used

How the correction factors (if used) are determined?

____

C11 If MC meters or probes are used for monitoring, check the following:

C11a Direction of grain relative to pins

- ☐ Pins inserted along the grain
- ☐ Pins inserted across the grain

C11b Pins penetration

[   ] (mm) [   ] thickness of lumber (mm)

C12 Auxiliary equipment

C12a Oven

- ☐ Commercial oven
- ☐ Home-made oven

- ☐ Oven has air circulation
- ☐ Oven without air circulation

- ☐ Do not have oven

C12b Balance for MC wafers

- ☐ Triple beam balance
- ☐ Electronic balance
- ☐ Self calculating balance
- ☐ Do not have a balance

[   ] precision (grams)

C12c Balance for sample boards

- ☐ Triple beam balance
- ☐ Electronic balance
- ☐ Self calculating balance
- ☐ Do not have a balance

[   ] precision (grams)

C12d Band-saw

- ☐ Band saw within 100ft
- ☐ Band saw more than 100 ft away
- ☐ Do not have a band saw

C12e Anemometer

- ☐ Hot wire anemometer
- ☐ Deflection anemometer
- ☐ Rotating vane anemometer
- ☐ Do not have an anemometer

C12f Hygrometer

- ☐ Sling psychrometer
- ☐ Electronic
- ☐ Stationary mounted
- ☐ Do not have hygrometer

C13 Process recordkeeping

- ☐ Records of past drying charges are mantained
  - ☐ Written records
  - ☐ Electronic records
- ☐ No records are kept

C14 Operating temperature of oven

Operating temperature ______ °C

C15 MC waffers dimensions

Along grain ______ mm

Accross grain ______ mm

Thickness ______ mm

D. KILN OPERATION

D1 Type of drying schedules

- ☐ Drying schedules specific for species and thicknesses
- ☐ Generic drying schedule for all species
- ☐ Operator does not use drying schedules

D2 Main source of drying schedules

- ☐ Kiln manufacturer
- ☐ Government, NGO or educational institution
- ☐ Developed in the company
- ☐ Fomr other companies
- ☐ Other ______________________

D3 Target moisture content determination

- ☐ Target MC defined by management
- ☐ Target MC defined by the kiln operator
- ☐ No formal definition of target MC
- ☐ Other ______________________

D4 Target moisture content values

Product	Moisture content
______	______
______	______
______	______

D5 Mixed loads

- ☐ Mixed loads are very unusual
- ☐ Mixed loads 3 or less times a year
- ☐ More than 3 mixed loads per year in same kiln

D6 Species usually mixed in same load

______ with ______

______ with ______

______ with ______

D7 Thicknesses usually mixed in a load (inch)

______ in with ______ in

______ in with ______ in

______ in with ______ in

D8 Moisture content of lumber before kiln drying

______ % green-off-the-saw material

______ % air-dried or pre-dried material

D9 Equalization

- ☐ Equalization step for all loads
- ☐ Equalization step for some loads
- ☐ No equalization step

D10 When does equalization start?

____

D11 Temperature and duration of equalization

Conditions ______

Temperature (^{o}C) ______

Duration(hrs) ______

D12 Conditioning

- ☐ Conditioning step for all loads
- ☐ Conditioning step for some loads
- ☐ No conditioning step

D13 When does conditioning start?

____

D14 Temperature and duration of conditioning

Conditions ______

Temperature (oC) ______

Duration(hrs) ______

E. DRYING QUALITY AND DRYING DEGRADE

E1 Moisture content of sample boards (inspect all sample boards in a load)

E2 Moisture content of dry lumber (check 20 boards with an electric moisture meter)

E3 Prong test (perform 3 prong tests)

- ☐ Prongs straight or slightly bent inward or outward
- ☐ Prongs touch or pass each other
- ☐ Severe reverse case-hardening
- ☐ No prong test performed

E4 End checks (inspect ends of 10 courses and count boards with end checks deeper than 50mm)

No. of boards ☐ Boards with checks >50mm ☐

E5 Surface checks (check ≥ 30 boards and record number of boards with visible surface checks)

No. of boards ☐ Boards with surf. checks ☐

E6 Warp (inspect ≥ 30 boards from the middle of the load and record boards with visible warp, >3mm)

No. of boards ☐ Boards with warp >3mm ☐

E7 Other drying degrade problems (ask operator or manager)

No.	Description of problem	Severity	Frequency
1	Honeycomb	☐ Mild ☐ Moderate ☐ Severe	☐ Rarely ☐ Ocasionally ☐ Frequently
2	Sticker stain or stain	☐ Mild ☐ Moderate ☐ Severe	☐ Rarely ☐ Ocasionally ☐ Frequently
3	Collapse	☐ Mild ☐ Moderate ☐ Severe	☐ Rarely ☐ Ocasionally ☐ Frequently
4	Over or under-drying	☐ Mild ☐ Moderate ☐ Severe	☐ Rarely ☐ Ocasionally ☐ Frequently
5		☐ Mild ☐ Moderate ☐ Severe	☐ Rarely ☐ Ocasionally ☐ Frequently
6		☐ Mild ☐ Moderate ☐ Severe	☐ Rarely ☐ Ocasionally ☐ Frequently
7		☐ Mild ☐ Moderate ☐ Severe	☐ Rarely ☐ Ocasionally ☐ Frequently
8		☐ Mild ☐ Moderate ☐ Severe	☐ Rarely ☐ Ocasionally ☐ Frequently

F. QUALITY CONTROL AND MANAGEMENT

F1 Which of the following best describes the objective of your drying operation (rate them from 1 to 3)

☐ Minimize drying degrade

☐ Maximize throughput

☐ Minimize drying costs

How is the quality control carried out?

____

____

____

____

____

F2 Estimated value loss due to drying degrade

☐ ☐ $US

☐ % of value

☐ Not estimated

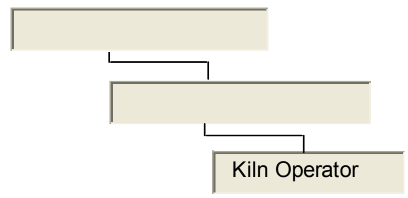
F3 How has the value in F2 been calculated?

☐ Rough estimate

☐ Sampling procedure

☐ Other ____________________________

F4 Describe where does the drying operation fits in the company's organizational structure



G. DRYING STORAGE AND MANUFACTURING PLANT

G1 Type of storage and floor

☐ Open without cover

☐ Open with roof

☐ Closed not conditioned

☐ Closed and conditioned

☐ Concrete floor

☐ Non-concrete floor

Type ______________

☐ Well mantained floor

☐ Some noticeable damage

☐ Floor severly damaged

☐ No wrapping is used

☐ Lumber is wrapped

Type ______________

G2 Conditions in storage area

Temperature ☐ °C

Relative humidity ☐ %

G3 Conditions in manufacturing plant (if any)

Temperature ☐ °C

Relative humidity ☐ %

COMMENTS

AREA	COMMENT

APPENDIX C EVALUATION CHECKLIST (SPANISH VERSION)

INFORMACION GENERAL

Empresa ________________________ Fecha (dd/mm/yy) __________

Ubicación ________________________

Contacto(s) ________________________

Actividad/productos ________________________

INFORMACION SOBRE CAMARA DE SECADO

Marca/fabricación local ______________ Origen ______________

Capacidad ______________ p.t. Antiguedad de horno ______________

Tipo de construcción

- ☐ Paneles de aluminio
- ☐ Mamposteria
- ☐ Madera

Fuente de energía

- ☐ Gas natural
- ☐ Desperdicio de madera
- ☐ Otro ______________

Control

- ☐ Manual
- ☐ Semi-automatico
- ☐ Automatico

Modo de carga

- ☐ En rieles
- ☐ En paquetes

A. CONDICION Y MANTENIMIENTO DE CAMARA

A1 Mantenimiento de acuerdo a un programa

- ☐ Mantenimiento de acuerdo a un programa
- ☐ Reparaciones e inspecciones cuando hay fallas

A2 Registro de trabajos de mantenimiento

- ☐ Trabajos de mantenimiento apropiadamente registrados
- ☐ No existen registros de mantenimiento

A3 Filtraciones en puertas, paredes y techo

- ☐ Filtraciones no visibles
- ☐ Pequeñas filtraciones
- ☐ Grandes filtraciones

A4 Condensación dentro de la cámara

- ☐ No existe evidencia de condensacion
- ☐ Problemas de corrosion debido condensacion o filtraciones
- ☐ Daño severo debido a condensacion

A5 Tipo de termómetros

- ☐ RTD (resistencia)
- ☐ Termocupla
- ☐ De bulbo (expansion de fluido)
- ☐ Bimetalico (expansion diferencial)

A6 Número de termómetros

- ☐ Termómetros de bulbo seco
- ☐ Bulbo humedo/placas de celulosa

A7 Ubicacion de termómetros de bulbo seco

- ☐ Sensores muy cerca de fuentes de cal
- ☐ Bulbo seco debajo de bulbo húmedo
- ☐ Sensor muy cerca de paredes o carga de madera
- ☐ Ubicacion de sensores no inspeccionada

A8 Frecuencia de cambio de tela de bulbo húmedo

- ☐ Para cada carga de secado
- ☐ Cambio de tela de bulbo humedo cuando sucia
- ☐ Rara vez
- ☐ No aplica

A9 Frecuencia de cambio de placas de celulosa

- ☐ Para cada carga de secado o deacuerdo a frabricante
- ☐ Solo cuando ocurren problemas
- ☐ Sin cambio desde instalación de cámara
- ☐ No aplica

A10 Calibración de sensores de temperatura

- ☐ Cada año o con mayor frecuencia
- ☐ Solo cuando ocurren problemas
- ☐ No calibrados desde instalación de cámara

A11 Velocidad de aire en el bulbo húmedo

- ☐ 300 ppm (1.5m/s) o mayor
- ☐ Entre 150 ppm (0.75m/s) y 300 ppm (1.5m/s)
- ☐ Menos de 150 ppm o flujo inexistente

A12 Flujo de agua al bulbo húmedo

- ☐ Flujo de agua y temperature apropiados
- ☐ Flujo es muy rápido o muy lento
- ☐ El sensor de bulbo húmedo toca el agua en el depósito
- ☐ Agua inusualmente fría o caliente
- ☐ No aplica (usan placas de celulosa)

A13 Operación de válvulas de paso de vapor

- ☐ Poco o ningun vapor pasa por la valvulas cuando cerradas
- ☐ Vapor pasa notoriamente cuando las valvulas estan cerradas
- ☐ No aplica

A14 Operación de válvulas de aspersión

- ☐ Vapor/agua jno pasan por válvula cerradas
- ☐ Vapor/agua pasan visiblemente por válvulas cerradas
- ☐ No aplica

A15\ Instalacion y ubicacion de trampas de vapor

- ☐ Trampas correctamente ubicadas (despues y debajo radiadores)
- ☐ Trampas dificilmente accesibles para mantenimiento

- ☐ Trampas individuales para cada radiador
- ☐ Más de una línea de radiador por trampa

- ☐ Filtros apropiadamente ubicados antes de trampas de vapor
- ☐ Filtros no fueron instalados

- ☐ No aplica

A16 Operacion de trampas de vapor

- ☐ Trampas trabajando apropiadame
- ☐ Trampas insuficientes para manejar condensado
- ☐ Una o mas trampas no estan operando
- ☐ No aplica

A17 Mantenimiento de trampas de va

- ☐ Mantenimiento cada año o con mayor frecuencia
- ☐ Mantenimiento ocasional cuando ocurren problemas
- ☐ Ultimo mantenimiento hace dos o más años
- ☐ No aplica

A18 Tipo de sistema de ventiladores

☐ Velocidad variable	☐ Motores externos	☐ Lineales	☐ Aspas tipo hélice	☐ Giro reversible
☐ Velocidad fija	☐ Motores internos	☐ Transversales	☐ Aspas de disco	☐ Giro no-reversible

A19 Piso de ventiladores

- ☐ Piso de ventiladores se extiende hasta borde de carga
- ☐ Piso de ventiladores no se extiende hasta borde de carga

- ☐ Piso de ventiladores puede soportar a personal de r
- ☐ Piso de ventiladores en mal estado

A20 Reversion de giro de ventiladores

- ☐ Reversión de giro ocurre normalmente
- ☐ Mas de 3/4 de las reversiones programadas
- ☐ Menos de 3/4 de las reversiones programdas
- ☐ Ventiladores no son reversibles

Reversión de giro cada ☐ horas

A21 Condiciones de ventiladores

- ☐ Ventiladores fijos en su caja sin daño visible en aspas
- ☐ Ventiladores no estan fijos en caja o existe daño visible en aspas
- ☐ Ventiladores en malas condiciones

A22 Velocidad de aire (pies por minuto)

Paquete				← Fila superior
Estiba				
Paquete				← Fila intermedia
Estiba				
Paquete				← Fila inferior

A23 Tipo de ventilas

☐ Ventilas en techo	☐ Ventilas modulables	☐ Control manual	☐ Ventilas normales
☐ Ventilas en costados	☐ Ventilas de dos posiciones	☐ Control automático	☐ Ventilas con ventiladores

A24 Filtraciones alrededor de ventilas

- ☐ Ventilas a la misma altura, sin filtraciones evidentes
- ☐ Pequeñas filtraciones en ventilas cuando cerradas (luz externa)
- ☐ Filtracion evidente por ventilas cuando cerradas

A25 Tamaño y número de ventilas

	Área estimada por ventila(cm^2)
	Número de ventilas

A26 Tipo de sistema de transmision de calor

- ☐ Vapor
- ☐ Aceite caliente
- ☐ Agua caliente
- ☐ Llama directa
- ☐ Resistencias eléctricas

A27 Tipo de serpentines

Tipo	Materiales: Tubos	Materiales: Aletas
☐ Simple	☐ Fierro	☐ Fierro
☐ Con aletas	☐ Aluminio	☐ Aluminio
	☐ Cobre	☐ Cobre

A28 Condiciones de los radiadores

- ☐ Limpios, sin materiales extraños
- ☐ Algo de suciedad y oxidación
- ☐ Severamente corrodias, cubiertos con materiales extraños

A29 Inclinacion de los radiadores

- ☐ Inclinación apropiada en dirección correcta
- ☐ Inclinación insuficiente
- ☐ Sin inclinación o inclinación en la dirección incorrecta

A30 Aislamiento de lineas de alimentacion de vapor

- ☐ Aislamiento en líneas de vapor correctamente instalado
- ☐ Aislamiento térmico notoriamente dañado
- ☐ Lineas de vapor no aisladas térmicamente

A31 Filtraciones en uniones, tuberias y radiadores

- ☐ Sin filtraciones visibles
- ☐ Pequeñas filtraciones
- ☐ Varias pequeñas y medianas filtraciones

A32 Tipo de sistema de humidificacion

- ☐ Vapor
- ☐ Aspersion de agua
- ☐ Otro ______________________

A33 Condiciones del sistema de humidificacion

- ☐ Boquillas producen aspersión uniforme
- ☐ Boquillas producen aspersion no uniforme o bloqueados

A34 Drenaje del piso del horno

- ☐ Buen drenaje, no existe agua en el piso del horno
- ☐ Mal drenaje, agua líquida en madera o piso de cámara

A35 Respuesta de la camara

Tiempo necesario para alcanzar temperaturas desde inicio		hrs		
Tiempo necesario para alcanzar temperaturas durante secado		hrs		
Temperatura (ºC)		deseado		real
Humedad relativa (%)		deseado		real

B. PRACTICAS DE APILADO

B1 Tipo, tamaño y material de separadores

- ☐ Sección rectangular
- ☐ Perfil especial
- ☐ Madera sólida
- ☐ Venesta o material alternativo

Ancho ____________ mm

Alto ____________ mm

Largos ____________ mm

B2 Especies de separadores y estibas

____________________ ____________________

____________________ ____________________

____________________ ____________________

B3 Contenido de humedad de separadores (20 pzas)

B4 Uniformidad de espesor de separadores (20pzas)

B5 Rectitud de separadores (mida alabeo en 20 pzas)

B6 Uniformidad de espesor de estibas (20pzas)

B7 Alineación de separadores (15 columnas) apunte cuantos estan fuera de alineacion

B8 Separadores faltantes (inspeccione 15 columnas apunte cuantos faltan en cada columna)

B9 Tamaño de paquetes y espacio entre separadores

Ancho ☐ cm
Alto ☐ cm
Largo (s) ☐ m

Espaciado separadores ☐ cm

B10 Método de apilado

- ☐ Madera de largo uniforme
- ☐ En caja
- ☐ Un extremo uniforme
- ☐ Dos extremos no uniformes

B11 Costado de paquetes

- ☐ Bien alineados
- ☐ Algunas capas no alineadas
- ☐ Mayoria no estan alineados

B12 Variación en espesor de tablas

- ☐ Separadores no flexionados por variación de espesor de tablas
- ☐ Algunas tablas no tocan separadores o éstos estan flexionados
- ☐ Apilado notoriamente irregular debido a variación de espesor

B13 Colocado de estibas (inspeccione 15 estibas)

- ☐ Estibas bien alineadas con columnas de separadores
- ☐ Tres o menos estibas fuera de alineamiento o faltantes
- ☐ Mas de 4 estivas fuera de alineamiento o faltantes

B14 Espacio de plénum (inspeccione un horno lleno)

Numero de separadores	
Numero de estibas	
Espesor de separadores (mm)	
Espesor de estibas (mm)	
Ancho de espacio de plénum (cm)	

B15 Uso de deflectores

- ☐ Deflectores hacen buen contacto con carga
- ☐ Algunos espacios de <15cm entre carga y deflectores
- ☐ Muchos espacios de 30cm o mayores
- ☐ Deflectores no utilizados

B16 Altura de paquetes y contacto con deflectores

- ☐ Parte superior de pilas hacen contacto uniforme con deflectores
- ☐ Alguna variación en altura de pilas
- ☐ Varias pilas no hacen contacto con deflectores
- ☐ Deflectores no utilizados

B17 Colocado de paquetes en una carga de secado

- ☐ Paquetes colocados apropiadamente, buen flujo de aire
- ☐ Flujo de aire no uniforme por colocado inapropiado
- ☐ Colocado inapropiado, causando cortos circuitos de aire

C. CONTROL DE PROCESO

C1 Control de proceso por:

- ☐ Contenido de humedad (peso o electrod
- ☐ Tiempo

C2 Número de muestras de control por carga

☐ muestras/electrodos por ☐ p.t.

C3 Seleccion de muestras de control

- ☐ Muestras son seleccionadas aleatoriamente
- ☐ Muestras representan piezas mas dificiles y fáciles de secar
- ☐ Otro criterio ______________________

C4 Sellado de testas de muestras de control

- ☐ Testas de muestras no selladas
- ☐ Sellado de testas con producto comercial
- ☐ Testas selladas con pintura a base de aluminio o alquitrán
- ☐ Adhesivo para madera
- ☐ No aplica

C5 Largo de muestras de control

☐ Largo (cm)

C6 Colocado de muestras de control

- ☐ En espacios dentro de la carga
- ☐ En espacios de estibas
- ☐ Muestras no estan dentro de la carga
- ☐ No aplica

- ☐ Ubicaciones representan distintas zonas en la cámara
- ☐ Muestras colocadas para facilidad de acceso
- ☐ No aplica

C7 Acceso a muestras de control

- ☐ Acceso seguro a muestras de control
- ☐ Alguna dificultad para acceder muestras
- ☐ Acceso a muestras dificil y no seguro
- ☐ No aplica

C8 Determinacion de C.H. inicial de muestras

- ☐ Método de secado en estufa
- ☐ Electrodos o medidores electricos
- ☐ Otros ______________________

C9 Determinacion de C.H. durante el secado

- ☐ Por peso
- ☐ Electrodos o medidores electricos
- ☐ Otro ______________________

C10 Factores de correccion para medidores de C.H.

- ☐ Lecturas son corregidas por especie y temperatura
- ☐ Lecturas son corregidas por especie
- ☐ Factores de corrección no son utilizados

Como determinan los factores de correccion a usar?

____

C11 Si se usan medidores electrico de C.H., observe lo siguiente

C11a Direccion de electrodos

- ☐ Electrodos a lo largo del grano
- ☐ Electrodos a través del grano

C11b Penetracion de electrodos

☐ (mm) ☐ espesor de madera (mm)

C12 Equipo auxiliar (laboratorio)

C12a Estufa

- ☐ Estufa comercial
- ☐ Estufa casera

- ☐ Estufa tiene circulación de aire
- ☐ Estufa no tiene circulación de aire

- ☐ No tienen estufa

C12b Balanza para probetas

- ☐ Balanza de brazo triple
- ☐ Balanza electrónica
- ☐ Balanza auto-regulada
- ☐ No cuentan con balanza

☐ precision (gramos)

C12c Balanza para muestras de control

- ☐ Balanza de brazo triple
- ☐ Balanza electrónica
- ☐ Balanza auto-regulada
- ☐ No cuentan con balanza

☐ precision (gramos)

C12d Sierra cinta

- ☐ Sierra cinta a menos de 30m
- ☐ Sierra cienta a mas de 30m
- ☐ No cuentan con cierra cinta

C12e Anemometro

- ☐ Anemómetro de alambre caliente
- ☐ Anemómetro de deflexión
- ☐ Anemómetro rotatorio
- ☐ No cuentan con anemómetro

C12f Hygrometro

- ☐ Psicrometro rotatorio
- ☐ Electrónico
- ☐ De bulbo seco y húmedo
- ☐ No cuentan con higrómetro

C13 Registro de proceso

- ☐ Se mantienen registro de cargas pasadas
  - ☐ Registros escritos
  - ☐ Registros electrónicos
- ☐ No se mantienen registros

C14 Temperatura operacional de la estufa

Temperature operacional ☐ °C

C15 Dimensiones de probetas

A lo largo del grano ☐ mm
A traves del grano ☐ mm
Espesor ☐ mm

D. OPERACION DE LA CAMARA

D1 Tipo de programas de secado

- ☐ Programas específicos para cada especie y espesor
- ☐ Programa genérico para todas las especies
- ☐ No se usan programas de secado

D2 Fuente principal de programas de secado

- ☐ Fabricante de la cámara
- ☐ Agencia de gobierno, ONG o institución educacional
- ☐ Desarrollados en la compañía
- ☐ De otras compañías
- ☐ Otros ______

D3 Determinacion del C.H. objectivo

- ☐ C.H. objetivo definido por administración
- ☐ C.H. objetivo definido por el operador
- ☐ No existe definición formal del C.H. objetivo
- ☐ Otro ______

D4 Valores de C.H. objetivo

Producto	Contenido de Humedad
______	______
______	______
______	______

D5 Cargas mezcladas

- ☐ Cargas mezcladas muy inusuales
- ☐ Cargas mezcladas 3 o menos veces al año
- ☐ Más de 3 cargas mezcladas al año

D6 Especies mezcladas en misma carga

______ con ______
______ con ______
______ con ______

D7 Espesores usualmente mezclados (pulgadas)

______ pulg con ______ pulg
______ pulg con ______ pulg
______ pulg con ______ pulg

D8 Contenido de humedad previo secado

☐ % madera verde
☐ % secado al aire o pre-secado

D9 Ecualizacion

- ☐ Ecualización para todas las cargas
- ☐ Ecualización para algunas cargas
- ☐ No realizan ecualización

D10 Cuando inicia ecualizacion?

______

D11 Condiciones y tiempo para ecualizacion?

Humedad Relativa ______ CHE ______
Temperatura (°C) ______ Duracion ______ hrs
Especie ______ Esp. ______

D12 Acondicionado (o liberación de tensiones)

- ☐ Acondicionado para todas las cargas
- ☐ Acondicionado para algunas cargas
- ☐ No realizan acondicionado

D13 Cuando inicia el acondicionado?

______

D14 Condiciones y tiempo para acondicionado?

Humedad Relativa ______ CHE ______
Temperatura (°C) ______ Duracion ______ hrs
Especie ______ Esp. ______

E. CALIDAD DE SECADO Y PERDIDAS

E1 Contenido de humedad de muestras de control (inspeccion todas las muestras de una carga)

E2 Contenido de humedad final de madera (mida 20 piezas con un medidor electrico)

E3 Prueba de tensiones (3 pruebas de tenedor)

- ☐ Deientes rectos o ligeramente inclinados (hacia adentro o afuera)
- ☐ Endurecimiento (dientes se tocan o se pasan uno respecto al otro)
- ☐ Reversión de tensiones severa (dientes hacia afuera)
- ☐ No se realizó prueba de tensiones

E4 Rajaduras en testas (observe extremos de 10 capas y cuente piezas con rajaduras > 50mm)

No. de piezas ☐ Piezas con rajaduras >50mm ☐

E5 Rajaduras superficiales (inspeccione 30 piezas y anote cuantos tienen rajaduras notorias)

No. de piezas ☐ Piezas con rajaduras ☐

E6 Torcedura (observe ≥ 30 piezas al centro de la carga, anote piezas con torcedura mayor 6mm)

No. de piezas ☐ Piezas con torcedura >6mm ☐

E7 Otros defectos de secado (pregunte a operador o supervisor)

No.	Descripcion del problema	Severidad	Frecuencia
1	Agrietamientos internos	☐ Ligero ☐ Moderado ☐ Severo	☐ Rara vez ☐ Ocasionalmer ☐ Frecuenteme
2	Mancha de separadores o manchas en general	☐ Ligero ☐ Moderado ☐ Severo	☐ Rara vez ☐ Ocasionalmer ☐ Frecuenteme
3	Colapso	☐ Ligero ☐ Moderado ☐ Severo	☐ Rara vez ☐ Ocasionalmer ☐ Frecuenteme
4	Sobre secado o secado insuficiente	☐ Ligero ☐ Moderado ☐ Severo	☐ Rara vez ☐ Ocasionalmer ☐ Frecuenteme
5		☐ Ligero ☐ Moderado ☐ Severo	☐ Rara vez ☐ Ocasionalmer ☐ Frecuenteme
6		☐ Ligero ☐ Moderado ☐ Severo	☐ Rara vez ☐ Ocasionalmer ☐ Frecuenteme
7		☐ Ligero ☐ Moderado ☐ Severo	☐ Rara vez ☐ Ocasionalmer ☐ Frecuenteme
8		☐ Ligero ☐ Moderado ☐ Severo	☐ Rara vez ☐ Ocasionalmer ☐ Frecuenteme

F. CONTROL DE CALIDAD Y ORGANIZACION DEL SECADO

F1 Cual de las siguientes opciones describe mejor el objetivo del secado en su operacion (del 1 al 3)

☐ Minimizar perdidas por defectos de secado

☐ Maximizar produccion

☐ Minimizar costos

Como se lleva a cabo el control de calidad?

____

____

____

____

____

F2 Valor perdido por defectos de secado

☐ $US

☐ % del valor inicial

☐ No estimado

F3 Como fue estimado el valor en F2?

☐ Estimado aproximac

☐ Por muestreo

☐ Otro ____________________

F4 Describa donde se encuentra la operacion de secado dentro de la estructura organizacional

[ ]
[ ]
Operador de secado

☐ Posición de operador en la organización claramente definida

☐ Operador no seguro de su posición en la organización

☐ Posición del operador en la organización no definida

G. ALMACENAMIENTO DE MADERA SECA Y PLANTA DE PROCESAMIENTO

G1 Tipo de area de almacenamiento de madera seca

☐ Abierta sin techo
☐ Abierta con techo
☐ Cerrada sin acondicionado
☐ Cerrado y acondicionado

☐ Piso de concreto
☐ Piso rustico
Tipo ____________

☐ Piso bien mantenido
☐ Algun daño en piso
☐ Piso severamente dañado

☐ No se usan cobertores individuales
☐ Madera es cubierta
Tipo ____________

G2 Condiciones en el area de almacenamiento

Temperatura [ ] °C

Humedad Relativa [ ] %

G3 Condiciones en la planta de procesamiento

Temperatura [ ] °C

Humedad Relativa [ ] %

COMENTARIOS

AREA	COMENTARIO

APPENDIX D EVALUATION REPORT – CIMAL IMR

GENERAL INFORMATION

Date of evaluation	**16-Dec-05**
Company's name	**CIMAL**
Contact(s)	**Pedro Murillo (Operator) and Fernando Velarde (Industrial Manager)**
Location	**Santa Cruz**
Main products/activity	**Garden furniture**

KILN INFORMATION

Brand	**Copcal and Seccea**				
Origin	**Italian**				
Capacity	**8 x 58K, 3 x 74K**	bd.ft.	Age of kiln(s)	**8 and 4**	years
Type of construction	**Aluminum panels and concrete**				
Energy source	**Natural gas**				
Control	**Semi-automatic**				
Loading	**Package-loaded**				

A. KILN CONDITION AND MANTEINANCE

A1	Type of manteinance	**According to a schedule**
A2	Maintenance recordkeeping	**Manteinance works are recorded regurarlly**
A3	Leaks in doors, walls and roof	**Small leaks are visible**
A4	Signs of condensation	**Corrosion problems due to condensation or leaks**
A5	Type of thermometers	**RTD type**
A6	Number of thermometers	
	Dry-bulb thermometers	**2**
	Wet-bulb thermometers	**2**
A7	Location of thermometers	**Location of temperature sensors not checked**
A8	Change wet-bulb wick	**Not applicable**
A9	Change of EMC waffers	**Changed for every load or according to manufacturer's schedule**
A10	Calibration of temperature sensors	**Calibration checks made every year or more often**
A11	Air speed across the wet-bulb	**Air flow could not be checked**
A12	Water flow to the wet-bulb	**Waterflow not checked**
A13	Steam valves operation	**Steam valves not checked**
A14	Steam spray valve operation	**Steam spray valve not checked**
A15	Steam traps location and installation	**Steam traps were not checked**
A16	Steam traps operation	**Traps were not checked**
A17	Steam traps manteinance	**Manteinance of steam traps very rare or unexistent**
A18	Type of fans system	**Variable speed** **Internal motors** **Cross-shaft fans** **Propeller-type fans** **Reversible fans**
A19	Fan floor	**Fan floor extends to edge of lumber pile** **Fan floor can support manteinance personnel**

A20	Fan reversal	**Reversals occurring as scheduled**	
		Fan reversal scheduled every 3 hrs	
A21	Conditions of fans	**Fans tight on shaft and no visible blade damage**	
A22	Air speed check		
	Max. speed through packs	**450** fpm **2.3** m/s	
	Min. speed through packs	**300** fpm **1.5** m/s	
	Range (Max - Min)	**150** fpm **0.8** m/s	
	Overall average airspeed	**373** fpm **1.9** m/s	
	Avrg. speed through packs	**373** fpm **1.9** m/s	
	Avrg. speed through bolsters	fpm m/s	

			Pack
			Bolster
450	300	300	Pack
			Bolster
400	410	380	Pack

A23	Type of vents	**Roof vents**
		Modulated vents
		Automatic control of vents
		Normal vents
A24	Leakage around vents	**All vents open to same height, no noticeable leaks**
A25	Size and number of vents	
	Area of individual vent	**600** cm^2 / vent
	Number of vents	**6** vents
	Total vent area	**3,600** cm^2
A26	Type of heating system	**Steam heated**
A27	Heating coils type (if applicable)	**Finned coils**
		Iron pipes and **Aluminum** fins
A28	Heating coils conditions	**Some dirt and rust**
A29	Slope of heating coils	**Slope of coils was not checked**
A30	Insulation of steam feedlines	**Steam feedlines properly insulated**
A31	Leaks in steam pipe and coils	**Small leaks**
A32	Humidification system type	**Both steam and water spray**
A33	Humidification system conditions	**Nozzles produce uniform steam**
A34	Drainage from kiln floor	**Good drainage, no liquid water inside the kiln**
A35	Set points and kiln response	
	Time necessary to reach set points from start-up	**12** hrs
	Time necessary to reach set points during operation	**1** hrs
	Set points minus actual conditions	Temperature **1** ºC
		Relative Humidity %

B. STACKING PRACTICES

B1	Stickers type		**Plain**
	Stickers material		**Solid wood**
	Stickers size	Width	**23, 28** mm
		Depth	**28, 23** mm
		Lengths	mm
B2	Species for stickers and bolsters		
			Tajibo **Cuchi**
			Roble
B3	Moisture content of stickers		
		Maximum	**10.5** %
		Minimum	**8.3** %
		Range	**2.2** %
		Average	**9.6** %
		Std Dev	**0.6** %
B4	Sticker thickness uniformity		

	Maximum	**22.8**	mm
	Minimum	**20.4**	mm
	Range	**2.4**	mm
	Average	**21.7**	mm
	Std Dev	**0.6**	mm
B5	Sticker straightness	**Very few or no stickers show significant crook**	
B6	Bolster thickness uniformity	**Very uniform thickness of bolsters**	
B7	Sticker alignment		
	Maximum	**3**	
	Minimum	**0**	
	Range	**3**	
	Average	**0.67**	
B8	Missing stickers		
	Maximum	**0**	
	Minimum	**0**	
	Range		
	Average		
B9	Size of packages and sticker spacing		
	Width		mm
	Height		mm
	Length(s)		mm
	Sticker spacing		mm
B10	Stacking method	**Even-one-end**	
B11	Side of packages	**Sides of packages perfectly aligned**	
B12	Lumber thickness variation	**Stickers not bent due to lumber thickness variation**	
B13	Bolster placement	**3 or less out of alignment or missing**	
B14	Plenum space		
	Plenum space should be	**1,081**	mm
	Measured	**1,100**	mm
B15	Baffle use	**No baffles are used**	
B16	Height of piles and baffle contact	**No baffles are used**	
B17	Package/pile placement in a load	**Packages properly placed, allowing good air circulation**	

C. PROCESS CONTROL

C1	Process control by	**Moisture content**
C2	Number of sample boards/probes	**6 y 8** per **58K, 74K** bf
C3	Selection of sample boards	**Wettest, thickest**
C4	End coating of sample boards	**No aplicable**
C5	Length of sample boards	**Full** cm
C6	Sample board placement	**According to kiln manufacturer**
		Sample boards located to represent different zones in the kiln
C7	Access to sample boards	
C8	Measurement of sample board initial MC	
		Electric meter
C9	Measurement of sample board MC during drying	
		By probes or electric meters
C10	Correction factors	**Readings are corrected for species**
	Correction factors determined by	**Species groups provided by kiln manufacturer**
C11	Use of electric probes to monitor moisture content	
	C11a Grain direction	**Pins inserted across the grain**

	C11b Penetration of pins		50%
C12			
	C12a	Oven	**Home-made oven**
			Oven without air circulation
	C12b	Balance for MC samples	**Electronic balance**
		Precission	**0.10** g
	C12c	Balance for sample boards	**Do not have balance**
		Precission	g
	C12d	Band-saw	**Band saw more than 100ft away**
	C12e	Anemometer	**Do not have an anemometer**
	C12f	Hygrometer	**Stationary mounted hygrometer**
C13	Process recordkeeping		**Record of past drying charges are mantained**
		Type of records	**Records in written format**
C14	Operating temperature of oven		**100** °C
C15	Size of MC waffers		**25.4** mm along the grain
			Varies mm accross grain
			Varies mm thickness

D. KILN OPERATION

D1	Type of drying schedules		**Drying schedules specific for each species**		
D2	Source of drying schedules		**Fabricante, consultoría y modificación**		
D3	Target mositure content determinatic		**Clientes**		
D4	Target mositure content values				
		Product	**All products**	MC	**12** %
		Product		MC	%
		Product		MC	%
D5	Mixed loads		**Mixed loads very unusual**		
D6	Species mixed in same load				
			with		
			with		
			with		
D7	Thicknesses mixed in same load (inches)				
			with		
			with		
			with		
D8	MC of lumber before kiln drying		**100** % green	% air-dried or pre-dried	
D9	Equalization		**Equalization always performed**		
D10	When does equalization start?		**When MC is close to target**		
D11	Equalization conditions				
		Conditions	**5% less than target MC**		
		Temp	**Last temperature of schedule**		
		Duration	**15-18 hrs**		
D12	Conditioning		**Conditioning always performed**		
D13	When does conditioning start?		**Wettest sample reaches target**		
D14	Conditioning temp and time				
		Conditions	**4-5% above target**		
		Temp	**65-70**		
		Duration	**6 days in Roble 2"**		

E. DRYING QUALITY AND DRYING DEGRADE

E1	MC of sample boards				
		Maximum		%	
		Minimum		%	
		Range		%	
		Average		%	
E2	MC of dry lumber				
		Maximum	**18.0**	%	
		Minimum	**4.2**	%	
		Range	**13.8**	%	
		Average	**7.9**	%	
		Std Dev	**3.8**	%	
E3	Prong test		**No prong test performed**		

F. QUALITY CONTROL AND MANAGEMENT

F1	Drying objectives rating	Minimize degrade	**3**
		Maximize throughput	**1**
		Minimize costs	**2**
	How is quality control carried out?		
		Prong tests for drying stressess	
		Measurements with pin meter for MC uniformity	
F2	Estimated value loss due to dryin degrade		
		Not estimated	
F3	Estimation of value in F2		

G. DRYING STORAGE

G1	Type of storage		**Open with roof**				
			Concrete Floor				
			Well maintained floor				
			No wrapping used				
G2	Sotarge conditions						
		Temperature	**32**	ºC			
		Relative humidity	**61.5**	%	EMC	**10.84%**	%
G3	Manufacturing plant conditions						
		Temperature		ºC			
		Relative humidity		%	EMC	**0.00%**	%

EVALUATION REPORT

In December 13th, 2005, Brian Bond and Omar Espinoza, researches of Virginia Polytechnic Institute and State University, as part of the Project for Improvement of Forest Management and Business Practices – coordinated by CADEFOR and BOLFOR -, visited the facilities of CIMAL IMR Ltd. to evaluate their lumber drying operation. The evaluation consisted of several questions to the kiln operator and measurements of important drying parameters. This report is a summary of what was observed during the mentioned visit. The detailed results are attached to this document.

DRY KILNS CONDITIONS AND MANTEINANCE

The maintenance of drying facilities and equipment is made according to a schedule and inspections and works are recorded.

The temperature registered by the kiln control panel was compared with our instruments, and a difference of 1°C in the dry-bulb temperature was observed, which falls within the acceptable variation.

Although the steam traps operation was not inspected, no maintenance was done for more than two years, which could eventually lead to their malfunction or failure, delaying the response of the kiln and even worse downtimes for repairs.

Air speed was measured in several locations inside one kiln with the following results: average velocity 1.9m/s (373 fpm), a maximum of 2.3m/s (450 fpm) and minimum of 1.5m/s (300 fpm). Some of the kilns have variable speed fans, which can allow the company to significant savings in energy costs, especially in the late stages of drying.

STACKING PRACTICES

The thickness of several stickers was measured, resulting in an average of 21.7mm and a range of 2.4mm, which is considered a moderate variation.

Regarding the MC of stickers, several were measured with the following results: average 9.1% and a range of 2.2%, being all readings below the maximum recommended.

No major problems were identified in the stacking practices, however, the company is currently using an even-one-end stacking, which reduces kiln capacity and can lead to airflow short-circuits. We recommend the experimentation with the box-piling method, which method is described in the literature attached to this document.

PROCESS CONTROL

Differences in MC of up to 5% between the probes and the oven-dry method were observed by the kiln operator, which suggests the need for calibration.

DRYING QUALITY

The MC of several boards was measured, with a resulting average of 7.9% and a standard deviation of 3.8%. A possible cause for this relatively high variation is the schedule currently used (high temperatures from the start-up and changes only in wet-bulb depression), which creates great differences in MC and stresses from the beginning which are difficult to normalize later. Although this variation is not considered critical for garden furniture, changing the current schedules by making the initial conditions milder can help to reduce the MC spread and shorten conditioning times.

APPENDIX E OM-43 DATALOGGER SPECIFICATIONS

OM-40 Series dataloggers can record temperature, relative humidity, 4 to 20 mA and 0 to 2.5 Vdc signals.

MEASUREMENT SPECIFICATIONS

<u>Temperature</u>

Measurement Range: sensor inside case, -20 to 70°C (-4 to 158°F); sensor outside case, -40 to 120°C (-40 to 248°F)
Sensor Type: thermistor
Accuracy: +0.7°C@21°C (+1.27°F @ 70°F) , see plot in detailed specs(PDF)
Resolution: 0.4°C (0.7°F) at 70°F
Response Time (Still Air): 15 min typical with sensor inside case; 1 min typical with sensor outside case

<u>Relative Humidity</u>

Measurement Range: 25% to 95% RH at 80°F for intervals of 10 seconds or greater, noncondensing and non-fogging, see plot in detailed specs(PDF)
Accuracy: ±5% 5 to 50°C (41 to 122°F)
Resolution: 0.4% 5 to 50°C (41 to 122°F)
Response Time: 10 min typical in air

Resolution: 0.4% of fs

GENERAL SPECIFICATIONS

Measurement Capacity: 7943 readings
Measurement Interval: user selectable from 0.5 sec to 9 hrs
Memory Modes: stop when wrap-around when full (user selectable)
Memory: non-volatile EEPROM memory retains data even if battery fails
Operation: blinking LED light confirms operation
Time Accuracy: ±1 minute week at 20°C (68°F)
Operating Temperature: -20 to 70°C (-4 to 158°F)
Operating Humidity: 0 to 95% non-condensing
Storage Temperature: -20 to 70°C (-4 to 158°F)
Power: 3.0 V lithium battery
Battery Life: 1 year
Dimensions: 68 H x 48 W x 19 mm D (2.4 x 1.9 x 0.8")
Weight: 29 g (1 oz)

APPENDIX F EMC CUSTOM FUNCTION VISUAL BASIC CODE

```
' EMC Estimator Custom Function

‘ Relative humidity in percentage, Temperature in oF

Function EMC(T, RH)

    RH = RH / 100

    W = 330 + 0.452 * T + 0.00415 * T ^ 2

    K = 0.791 + 0.000463 * T - 0.000000844 * T ^ 2

    K1 = 6.34 + 0.000775 * T - 0.0000935 * T ^ 2

    K2 = 1.09 + 0.0284 * T - 0.0000904 * T ^ 2

    EMC = ((1800 / W) * ((K * RH / (1 - K * RH)) + (K1 * K * RH + 2 * K1 * K2 *
(K ^ 2) * (RH ^ 2)) / (1 + K1 * K * RH + K1 * K2 * (K ^ 2) * (RH ^ 2)))) / 100

End Function
```

VITA

Omar Alejandro Espinoza Manzaneda was born in Cochabamba, Bolivia in June 17, 1973, and graduated as a Production Engineer from the Universidad Privada Boliviana in 1998. From 1997 to 2004 he worked as a Production Manager in a wood-doors manufacturing company in Cochabamba. In 2004, Mr. Espinoza received a Masters degree in International Business from the Florida International University and, during fall of the same year he started a Master of Science program in Wood Science and Forest Product at Virginia Tech.