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Drying of Wood from *Mimosa scabrella, Eucalyptus dunnii* and *Tectona grandis* in Solar Kiln, in South Brazil

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ABSTRACT

Background: The choice of a particular method of drying influences the drying time, quality of drying material and also on obtaining the desired moisture content for a particular purpose. It is possible to reduce the drying time and the incidence of defects when the process is conducted in an appropriate manner. Solar kiln drying is a method that has been was developed between the late 1950 and early 1960. This method is an intermediary between the air-drying and in conventional kiln drying. The main features of this method are the low operating costs and a partial control of the drying conditions. Solar kiln drying is an alternative to methods that have high costs of investment, maintenance and energy consumption. The fact of the studied species present desirable characteristics for the use of wood in the form of sawn, in addition to the absence of studies relating to drying, configures itself as relevant to search for such information. **Objective**: This study aimed to evaluate the drying of wood from bracatinga (*Mimosa scabrella* Benth), eucalypts (*Eucalyptus dunnii*) and teak (*Tectona grandis* L. f) in the solar kiln. **Methodology:** To do so, boards of the respective species with 25 mm thickness were used, and monitored the loss of moisture in control samples, assessing the mass loss of the woods weekly. **Results:** The woods hard a apparent specific gravity at 12% of moisture content of 0.55; 0.79 and 0.58 (g.cm^{-3}), respectively for *Mimosa scabrella, Eucalyptus dunnii* and *Tectona grandis*. These species reached a final moisture content of 10.36; 10.85 and 11.49%, being that the drying time was 119; 98 and 92 days with drying rate of 0.37; 0.19 and 0.73 (% .day^{-1}), respectively, for the studied species. In relation to environmental variables, the temperature of the interior d solar kiln has always been high than the average temperature of the external environment, even during nocturnal periods. **Conclusions:** Regarding the drying tensions, the wood of *Tectona grandis* did not develop drying tensions however the timber *Mimosa scabrella* and *Eucalyptus dunnii* developed drying stresses classified as mild and strong.

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INTRODUCTION

The drying process of wood is of fundamental importance in the production chain and is responsible for adding value to manufactured wood products, as well as improve a workability characteristics and reducing both the dimensional movement and the possibility of attack by wood-destroying organisms (Andrade *et al*., 2001; Klitzke *et al*., 2008).

However, the drying process of wood in conventional solar kiln involves high industrial costs, which leads to constant research aimed at improvement of the process, both on the efficiency of the equipment used, and the quality of dry wood. Considering the costs involved in raw material and fixed costs of the drying operation, driving the solar drying using, solar kiln must be carefully planned and executed in order to obtain success, particularly

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as to the quality of the final product (Olandoski *et al*., 1998; Stangerlin *et al*, 2012).

Brazil by being a tropical country and therefore favored from the standpoint of solar radiation, presents values of insolation around 2500 h/year and an average radiant power 1000 $W.m^2$, which promotes the use of solar dryers to remove moisture from wood (Santini, 1981; Mendes, 1985).

These solar kiln are built on a timber frame covered with a transparent or translucent film in order to promote the sunlight inside. Its operation is by a system of solar energy collection from short waves for heating the air which mainly occurs by convection, and a system for distribution of heated air occurs by forced ventilation (Wengert, 1971; Lumley; Choong 1981; Santini 1981; Viehbeck, 1999).

These solar greenhouses can be divided into two basic models: one with solar collector included in the structure and the other with the sink on the outside of the oven (Bauer, 2003). The solar greenhouses equipped with internal collectors are more widespread and its main features are the low cost, ease of construction and operation (Plumptre, 1979)

Already in solar kiln which have collectors external the heat transfer occurs through ducts, in which the heated air is conducted into the interior of the drying chamber and the cold air returns to the sink by forced circulation which can be performed manually or automated (Read *et al*., 1974;. Chen; Rosen, 1979; Steinmann *et al*., 1980; Robbins, 1983; Sattar, 1993; Stangerlin *et al*., 2012)

Plumptre (1979) and Santini (1981) reported that the main characteristics of solar greenhouses are good quality dry wood, obtaining moisture contents below the equilibrium humidity of the region and the time required for drying is lower than outdoor drying. Santini (1981) further supplements that the time required for drying a load of wood in solar greenhouse, besides the drying factors are also affected by the location and climatic conditions.

Thus was developed this study to evaluate the drying woods of bracatinga (*Mimosa scabrella*), eucalypts (*Eucalyptus dunnii*) and teak (*Tectona grandis*) in the solar greenhouse, Brazil.

MATERIALS AND METHODS

Collection and preparation of material:

Timbers were used of bracatinga (*Mimosa scabrella*), eucalypts (*Eucalyptus dunnii*) and teak (*Tectona grandis*), obtained from homogenous populations, being the tablets (with 25 mm thick).

The woods of bracatinga (Mimosa scabrella), eucalypts (Eucalyptus dunnii), were stacked in solar kiln in conjunction.

Monitoring moisture content and drying rate:

For monitoring the moisture content of wood assessed during the drying period four control samples were used for each species with 25 x 150 x 450 mm dimensions (thickness x width x length)

After cutting the boards to obtain the control samples, the tops were sealed with sealant (to minimize the water loss by the tops) and their masses were measured in electromechanical scale with a capacity of 6000g ± 0.5g precision obtaining the initial mass.

Control samples were placed in different locations of easy removal and replacement, to allow a real and representative measurement of the moisture content of the same. The monitoring of moisture content was carried out by weighing the control samples, performed weekly.

The drying rate was obtained according to the recommendations of Simpson (1991). Being quantified the rate of drying to the loss of capillary water (above the saturation point of the fiber - PSF%) and hygroscopic (below the PSF%)

Determination of the density of wood:

The determination of the apparent specific gravity at 12% of humidity was performed by stereometric method, in which samples of dimensions 20 x 20 x 30 mm (radial x tangential x longitudinal) kept in a climatic chamber at 20 ± 2°C and 65 ± 5% of relative humidity until the stabilization of all samples at 12% of moisture. Was determined the apparent specific gravity to 12% of all species evaluated as recommended by the Brazilian Regulatory Standard - NBR 7190 from Brazilian Association of Technical Standards - ABNT (1997).

Determination of initial, final moisture, moisture gradient and internal tensions:

To determine the final moisture content, moisture gradient and internal stresses were used 5 boards for each species from which three samples of 25 mm in length was obtained.

The moisture content of the boards after drying was obtained according to the recommendations of NBR 7190 (1997). The determination of moisture gradient and internal stresses (fork test) after drying was performed as recommended by Simpson (1991), and the internal stresses performed after acclimatization for a period of 24 hours in a climatic chamber at 20°C and 65 ± 5% relative humidity.

Given the mass datas of the control samples, charts were made for comparison of weight loss and moisture content For the evaluation of the rate of drying was performed analyzes of variance and regression. Measures of suitability and selection of regression models were carried out by analyzing the coefficients of determination (R^2) and visual analysis of the graphs for each species. To assess the degree of significance of the variables, as well as checking the variation between the drying rates and the apparent density at 12% of humidity of each species when significant, was applied the Tukey test at 5% of significance level to compare the averages.

RESULTS AND DISCUSSION

Specific gravity apparent 12% of wood:

It is observed in Table 1 that there was no statistical difference in the apparent specific gravity at 12% of humidity between *Mimosa scabrella* and *Tectona grandis* with 0.55 g.cm^{-3} and 0.58 g.cm^{-3} respectively, and the *Eucalyptus dunnii* presented statistical difference compared with other species, and with a higher value specific gravity at 12% (0.79 g.cm^{-3}).

Table 1: Apparent density of *Mimosa scabrella, Eucalyptus dunnii* and *Tectona grandis*.

Species	Specific gravity apparent 12% (g.cm^{-3})
Mimosa scabrella	0,55 a (0,03) (4,95)
Eucalyptus dunnii	0,79 b (0,06) (6,99)
Tectona grandis	0,58 a (0,03)(4,95)
F	66,47**

Values in brackets correspond to the standard deviation and the coefficient of variation, respectively. **Significant at 1% probability. Means followed by the same lowercase letter do not differ (Tukey p ≥ 0.05).

The specific gravity apparent at 12% of humidity of woods from *Mimosa scabrella* was close to the values found by Quartaroli *et al.*, (Sd), who found 0.53 g.cm^{-3}, in stands located in the Irati region of Paraná State in Brazil. Sturion; Silva (1989) also studding wood from *Mimosa scabrella* found (0.51 g.cm^{-3}) of apparent density at 12% of humidity, however, Carvalho (2003) obtained results relatively high (0.61 g.cm^{-3}) when compared with the apparent density of *Mimosa scabrella* found in this research.

The values of apparent density at 12% of humidity from *Eucalyptus dunnii* were similar to those described by Lopes *et al*. (2011), being the 0.78 g.cm^{-3} and Lima (2005) presented consistent values with the values found in this study. Batista *et al*. (2010) found lower values, which correspond to 0.56 g.cm^{-3}, as well as the values presented by Rocha (2001; 2002) of 0.65 g.cm^{-3}.

Evaluating the *Tectona grandis* wood the values of apparent density at 12% humidity (0.58 g.cm^{-3}) are similar to those described by Govaere *et al*. (2003), being the 0.61 g.cm^{-3}, in young wood. Already Lima *et al*. (2009) found values from 0.62 to 0.66 g.cm-3 depending on the spacing used in planting. As the figures presented by Roque; Ledesma (2006); Moya; Perez (2008) and Motta (2011) were similar to those described in this study.

Moisture content, time and rate of drying of wood:

The wood from bracatinga (*Mimosa scabrella*) began the process of drying in solar kiln with initial moisture content of 96.79% of the load, finishing the drying process after 119 days with a moisture content of 10.36%. With 37 days of drying in solar kiln the wood *Mimosa scabrella* reached the saturation point of fibers (PSF%), having a drying rate of 0.49 (%·day⁻¹) for this period. however, from the PSF (%) until the stabilization period of the moisture content in the wood from bracatinga (*Mimosa scabrella*) (10.36%) it took 82 days of drying. about 3.2 times more, resulting in a drying rate for the movement of hygroscopic water of 0.22 (%·day⁻¹). The higher drying rate above the PSF (%) occurs due to the movement of water into the timber by capillarity exceeds the movement of hygroscopic water (Kollmann; Côté Junior, 1968; Simpson, 1991; Siau, 1995; Klitzke, 2007). Silva *et al*. (1997) also point out that in drying conducted at low temperatures (air drying and drying in solar greenhouse) for most species, there is loss of half the moisture content from the first 30 days of drying. The remaining is eliminated in a 3 to 5 times higher, and the boards remain under the same exposure conditions. This is a consequence of the state of the wood moisture, since the capillary forces are weaker causing the evaporation of water contained in the capillaries of the cell lumens and cavities more easily. Concurrently, the same does not occur with the hygroscopic water which has a colloidal combination with the wood substance itself being so strongly held than capillary water (Gomide, 1974; Stangerlin *et al*., 2012).

Table 2: Moisture content, time and drying rate for the woods of *Mimosa scrabella*, *Eucalyptus dunnii* and *Tectona grandis* dried in solar greenhouse.

Species	Moisture content of initial (%)	Moisture content of final (%)	Drying (days)	Drying rate (%·days⁻¹)		
				> 30%	< 30%	Total
Mimosa scrabella	96.79 b	10.36 a	119 b	0,49 b	0,22 b	0,37 b
Eucalyptus dunnii	38.18 a	10.85 a	98 a	0,24 a	0,17 a	0,19 a
Tectona grandis	115.44 c	11.49 a	92 a	0,95 c	0,51 c	0,73 c

Means followed by the same letter in the vertical do not differ (Tukey p ≥ 0.05).

Already the wood of *Eucalyptus dunnii* (Table 2) began the process of drying in solar kiln with initial moisture content of 38.18% in the load, finishing the drying cycle in 114 days with final moisture content of 10 85%. Given that the humidity of the wood (38.18%) were close to the PSF (%) with a period of 16 days drying the wood reached 29.19% of moisture content, getting a drying rate for this fluid flow (capillary water) of (0.24 %$\cdot$day^{-1}).

For the movement of fluid below the fiber saturation humidity was 98 days, getting a drying rate of (0.17 %$\cdot$day^{-1}). This low rate of drying to this wood is a function for *Eucalyptus sp*. be refractory woods (Kollmann, 1959; Calonego *et al*., 2006; Oliveira *et al*., 2010; Souza *et al*., 2012).

For *Tectona grandis*, the initial moisture content was 115.44%, with the drying cycle in solar kiln finalized after 92 days, having the woods 11.49% of moisture content (Table 2). With 42 days of drying the woods showed a drying rate of 0.95 (%$\cdot$day-^{1}), period corresponding to the flow of fluid above the PSF (%), whereas for movement of hygroscopic water until the stabilization period at 11.49% of moisture was 50 days with drying rate of 0.51 (%$\cdot$day^{-1}). These differences in drying rate between species evaluated (*Mimosa scabrella*, *Tectona grandis* and *Eucalyptus dunnii*) are due to the anatomical feature intrinsic to the species, as well as factors inherent to the drying environment. Wherein for drying wood in solar greenhouses sunshine, solar radiation, air velocity and temperature inside the greenhouse are important (Troxell; Mueller, 1968; Gough, 1977; Santini, 1981; Jankowsky, 1990; Stangerlin *et al*., 2012)

Haque (2002) recounts the difficulty of obtaining low contents of moisture to dried wood in solar greenhouses, especially in winter periods. This author performing drying using solar greenhouses in Australia in the winter, finished drying for their species evaluated in 19% humidity on a 55 days period. So the woods studied in this work (*Mimosa scrabella*, *Eucalyptus dunnii* and *Tectona grandis*) remained these long periods (119; 114 and 92 days) within the solar kiln in order to verify the minimum moisture content reached by the woods to the region of Curitiba, states Paraná in south of Brazil.

For the drying rate (Table 2), which comprises the difference between the level of initial and final moisture content of wood in relation to time, as Kollman; Cote Junior (1968); Simpson (1991); SIAU (1995); Klitzke; Batista (2010) the initial moisture content of the wood influences particularly in the early stages of drying in which water evaporation occurs capillary form, and this stage observed the highest rates of drying.

Due to the characteristic of drying in solar kiln the temperatures did not exceed 55°C and in night periods the timber suffered packaging, and drying rates (Figure 1) for the boards of wooden evaluated were low (0.37; 0,19 and 0.73 %$\cdot$day^{-1}) for woods the *Mimosa scabrella*, *Eucalyptus dunnii* and *Tectona grandis* respectively. Another factor that contributes to these drying rates is the season in which the wood has been drying, corresponding to winter moreover, drying in solar kiln has not meant to be a method of accelerated drying as the drying conventional greenhouses.

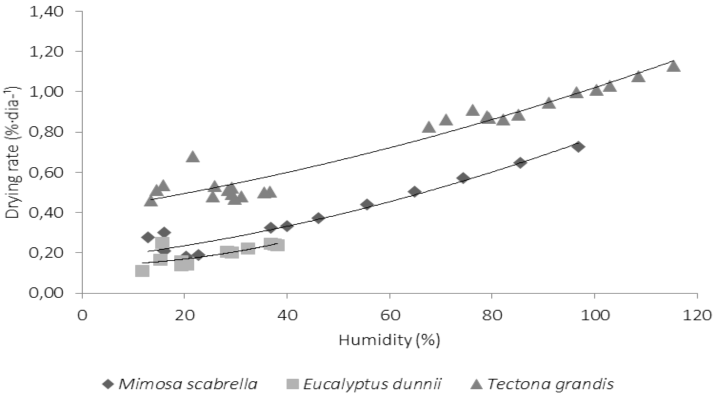

Fig. 1: Rate of drying of *Mimosa scabrella*, *Eucalyptus dunnii* and *Tectona grandis* and in solar greenhouse.

The models (Table 3) describe the behavior of drying in solar greenhouses for the three tested species (*Mimosa scabrella*, *Eucalyptus dunnii* and *Tectona grandis*) in which significant models were found at 95% of confidence level, having correlation between the rate of drying and the moisture content of wood, shown by the coefficients of determination (R²), and the values of standard error (Syx) demonstrating that the fit of polynomial models were suitable for drying wood in solar greenhouse.

Table 3: Equations adjusted for the rate of drying woods of *Mimosa scabrella, Eucalyptus dunnii* and *Tectona grandis* in solar greenhouse.

Species	Ajusted models	F	S_{yx}(%)	R²
Mimosa scabrella	Dr = 3E-5x^2+0,0029x+0,1647	49,25*	22,09	0,94
Eucalyptus dunnii	Dr = 7E-05x^2+0,0002x+0,1384	5,38*	18,90	0,54
Tectona grandis	Dr = 2E-05x^2+0,0039x+0,4083	185,26*	8,03	0,94

Dr: Drying rate (%$\cdot$day^{-1}); F: value F calculated; Syx (%): standard error of estimate; R²: coefficient of determination; *significant at 5% level of probability.

Stangerlin *et al*. (2012) evaluating the behavior of three species of *Eucalyptus* in two drying methods (solar, natural) received satisfactory correlations in their analyzes, which also differed statistically, as in the present study there're correlations between the moisture content and drying rate for the studied species.

It is also important to note that the anatomical structure of the wood, as well as their chemical constitution, also influences the rate of drying. The lowest rates were observed for drying the wood of *Eucalyptus dunnii* that has pits and small diameter of vessels normally blocked by tyloses, being considered genus with refractory woods (Stöhr, 1977; Vermaas, 2000; Stangerlin *et al*., 2012). Galvão; Jankowsky (1985) also emphasize that the loss of moisture from the wood when its moisture content is above the PSF (%) depends on the permeability (anatomical structure) and the characteristics of the air stream (temperature, relative humidity and velocity of displacement). Subsequently, the first phase of decreasing rate depends on permeability and density of the material, while the second phase of decreasing drying rate depends almost exclusively on the density.

Thus, we can say that the drying rate depends more on the characteristics of timber than the temperature and relative humidity air, the drying process must necessarily be adjusted to the wood being processed.

Another factor that justifies these low values found for the rate of drying of wood is the moisture content at which the samples were taken from the solar kiln (10.36; 10.85 and 11.49%) respectively for the woods of *Mimosa scabrella*, *Eucalyptus dunnii* and *Tectona grandis* (Figure 2). Several authors (Chen; Rosen, 1979; Haque, 2002; Bauer, 2003; Rodríguez *et al*., 2003) evaluating the behavior of the solar kiln found drying times lower than this work (Figure 2), approximately 30 to 55 days, but the final moisture content of the wood these authors were higher than 15% in coniferous wood.

Wood density also influences the behavior of drying, the wood of *Mimosa scabrella*, *Eucalyptus dunnii* and *Tectona grandis* showed apparent density at 12% of 0.53; 0.72 and 0.58 (g.cm^{-3}) respectively.

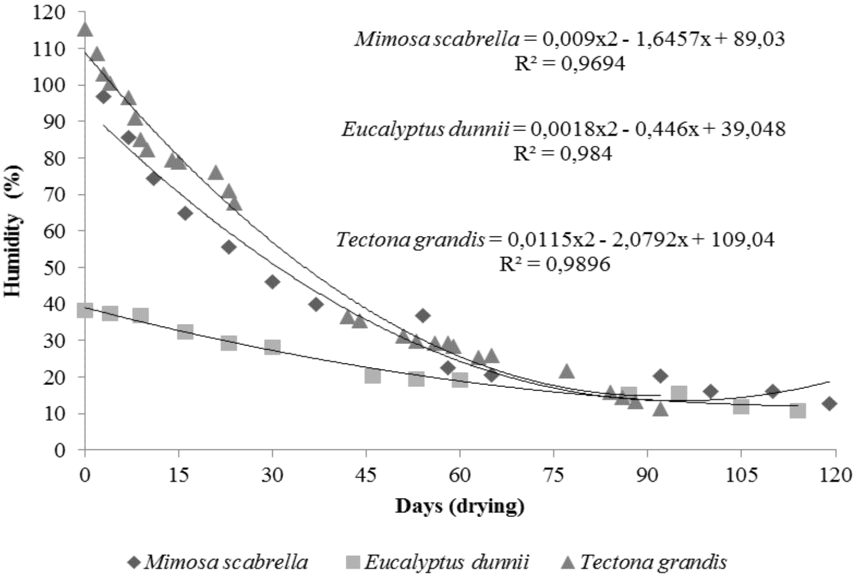

Fig. 2: Time taken for drying Woods of *Mimosa scabrella, Eucalyptus dunnii* and *Tectona grandis* in solar greenhouse.

Similar drying times found in this study were obtained by ONO *et al*. (2006); ONO; Venturino (2006); ONO (2006) in the woods of *Eucalyptus grandis* at 80 days, *Eucalyptus tereticornis* (108 days) and *Eucalyptus camaldulensis* (76 days) in which the final moisture content of the wood was 12%.

Several investigators (Read *et al*, 1974; Sharma *et al*, 1974; BOIS, 1977; GOUGH, 1981, Kennedy, 1984; Tschernitz; Simpson, 1985; Sattar, 1993 STANGERLIN *et al*, 2012) studding solar greenhouses, reported that the drying time is about two to five times faster than that observed in drying carried outdoors, for wood of the same thickness.

The moisture gradient and the classification of the type of drying tension provided by fork test for the species evaluated (*M. scabrella* , *T. grandis* and *E. dunnii*), are presented in Table 4, where it is observed that the wood from *M. scabrella* had the lowest moisture gradients (0.32%), while the *T. grandis* wood was observed larger moisture gradient (1.15%), and the timber of *E. dunni* had a moisture gradient of (0.57%), respectively.

Table 4: Moisture Gradient and drying stresses in woods of *Mimosa scabrella*, *Eucalyptus dunnii* and *Tectona grandis*.

Species	Moisture gradient (%)			Drying stresses (%)		
	1	2	Média	Smooth	Strong	Clear
Mimosa scabrella	0,28	0,36	0,32	20	0	80
Eucalyptus dunnii	0,52	0,63	0,57	40	60	0
Tectona grandis	1,40	0,89	1,15	0	0	100

For the stresses of drying, we note that the wood of *Tectona grandis* showed a 100% of boards free of tension, due to the drop in temperature that occurs in solar kiln during night periods, causing the packaging of woods. Already the woods of E*ucalyptus dunni*, showed up some kind of tension drying, characterized as Strong tensions in 60% of the assessed boards and others 40% as smooth tension. The timber of *Mimosa scabrella* was characterized as free of stresses or drying tension in 80% of evaluated boards, however, 20% of them had a smooth drying tension.

Drying environment:

Regarding to environmental variables, it can be seen from (Figure 3) that the drying environment of the solar kiln is more severe than the ambient outdoor conditions, where the daily temperature within the solar kiln over the period of drying always been superior to external conditions. Which was also observed for the relative humidity, that was always higher than the relative humidity inside the solar kiln, regardless the humidity of the woods, these observations were also noted by Santini (1981); Reuss *et al*. (1997); Stangerlin *et al*. (2012).

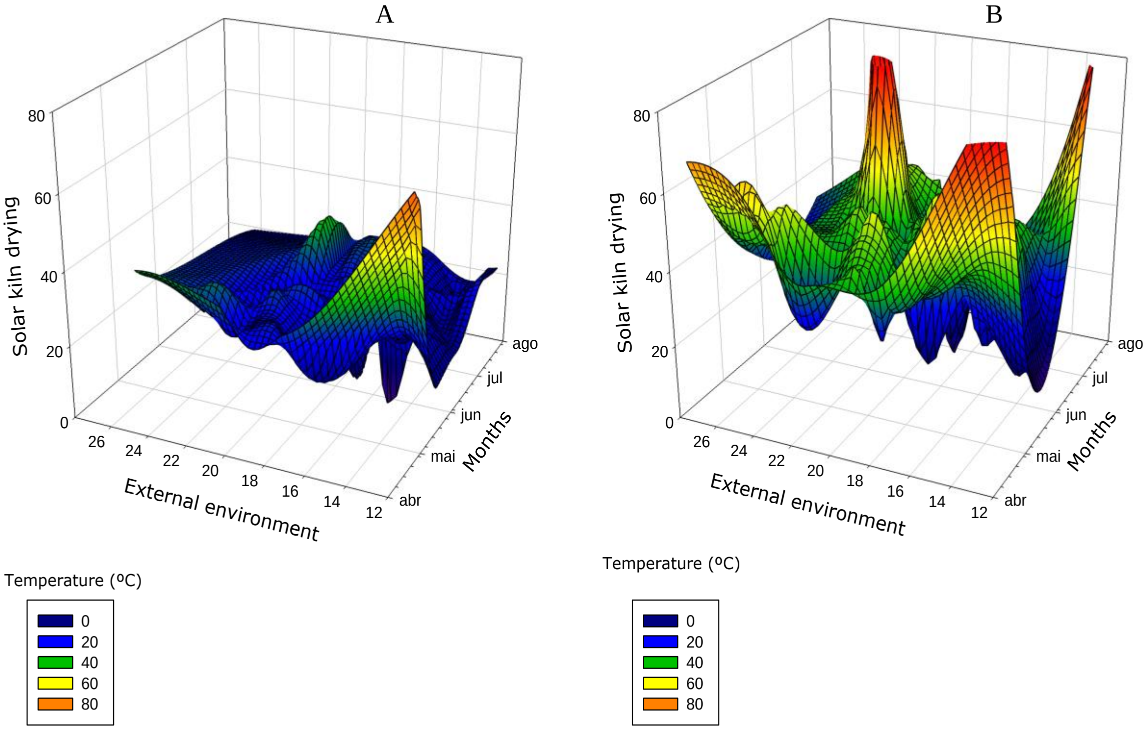

Fig. 3: Temperatures internal and external medium (A) and temperatures internal and external maximum (B) of solar kiln dryer and external environment.

Another relevant factor is the absorption of energy in form of heat provided by the solar kiln over the period of drying of wood from *Mimosa scabrella*, *Eucalyptus dunnii* and *Tectona grandis* maintaining this heat throughout the day. That higher temperatures were obtained within the solar greenhouse, along with lower relative humidity in comparison with the maximum temperatures and maximum relatives humidity’s outside.

Conclusion:

The wood from bracatinga *(Mimosa scabrella*) at the end of drying reached a moisture content of 10.36%, with a period of 119 days, having a drying rate of 0.37 (% $\cdot$day^{-1}).

The timber of eucalypts (*Eucalyptus dunnii*) finished the drying process at 114 days with final moisture content of 10.85% and a drying rate of 0.19 (% $\cdot$day^{-1}).

For wood of teak (*Tectona grandis),* with 92 days timbers reached a moisture content of 11.49% and a drying rate of 0.73 (% $\cdot$day^{-1}).

Regarding the stress supplied by drying *Tectona grandis* wood did not develop drying stresses; however, the timber of *Mimosa scabrella* and *Eucalyptus dunnii* developed drying stresses classified as mild and strong.

REFERENCES

Andrade, A., I.P. Jankowsky, M. Ducatti, 2001. Agrupamento de Madeiras para Secagem Convencional. Scientia Forestalis, Piracicaba, 59: 89-99.

Associação Brasileira de Normas Técnicas, NBR 7190, 1997. Projeto De Estruturas De Madeira. Anexo B - Ensaios De Caracterização. Rio de Janeiro.

Bauer, K., 2003. Development and Optimisation of a Low-Temperature Drying Schedule for *Eucalyptus grandis* (Hill) ex Maiden in a Solar-Assisted Timber Dryer. Tese (Doutorado em Ciências Agrárias) – Fakultät Agrarwissenschaften der Universität Hohenheim, Hohenheim.

Bois, P.J., 1977. Constructing and Operating a Small Solar-Heated Lumber Dryer. Madison: Forest Products Utilization: Technical Report, 7, United States Department of Agriculture – USDA, Forest Service.

Calonego, F.W., E.T.D. Severo, A. Coneglian, R.M. Barreiros, 2006. Qualidade da secagem de *Eucalyptus grandis* Mediante Vaporização Simultânea em Toros e em Madeira Serrada. Silva Lusitana, Lisboa, 14(2): 169-180.

Carvalho, P.E.R., 2003. Espécies Arbóreas Brasileiras. Colombo, PR: Embrapa Florestas.

Chen, P.Y.S., H.N. Rosen, 1979. Drying Yellow-Poplar in a Highly Efficient Solar kiln. In: 30thAnnual Western Dry Kiln Clubs. Proceedings, pp: 23-32.

Batista, D.C., R.J. Klitzke, C.V.T. Santos, 2010. Densidade Básica e Retratibilidade da Madeira de Clones de Três Espécies de *Eucalyptus*. Ciência Florestal, Santa Maria, 20(4): 665-674.

Galvão, A.P.M., I.P. Jankowsky, 1985. Secagem racional da Madeira. São Paulo: Nobel.

Gomide, J.L., 1974. Secagem da madeira. Viçosa: Universidade Federal de Viçosa – UFV-Minas Gerais.

Gough, D.K., 1977. The design and operation of a solar timber kiln. Suva: Fiji Timbers and their uses. Technical paper, Department of Forestry, 67: 17.

Gough, D.K., 1981.Timber Seasoning in a Solar Kiln. Technical paper 24. Department of Forestry, Queensland.

Govaere, G., I. Carpio, L. Cruz, 2003. Descripción Anatómica, Durabilidad y Propiedades Físicas y Mecánicas de *Tectona grandis*. Laboratorio de Productos Forestales, Universidad de Costa Rica, Disponível em: <http: //www.una.ac.cr/inis/docs/teca/temas/ARTICULO%20LPF%201.pdf>. Acessoem: 29 set. 2014.

Haque, M.N., 2002. Modelling of Solar Kilns and The Development of an Optimised Schedule for Drying Hardwood Timber. Tese (PhD in Chemical Engineering) –Universityof Sidney, Sidney.

Jankowsky, I.P., 1990. Fundamentos de Secagem de Madeiras. Piracicaba, 10.

Kennedy, J., 1984. Solar Kiln Seasoning of White Cypress Pine. Report 15, Department of Forestry, Queensland.

Klitzke, R.J., 2007. Secagem da Madeira. In: José Tarcísio da Silva Oliveira, Nilton César Fiedler, Marcelo Nogueira. (Org.). Tecnologias Aplicadas ao Setor Madeireiro. Visconde do Rio Branco: Suprema Gráfica e Editora Ltda, 1: 271-366.

Klitzke, R.J., D.C. Batista, 2010. Ensaio de Taxa de Secagem e Escore de Defeitos Para a Predição da Qualidade de Secagem Convencional da Madeira de *Eucalyptus*. Scientia Forestalis, Piracicaba, 38(85): 97-105.

Klitzke, R.J., D.L. Savioli, G.I.B. Muñiz, D.C. Batista, 2008. Caracterização dos Lenhos de Cerne, Alburno e Transição de Jatobá (*Hymenaea* sp.) Visando ao Agrupamento para Fins de Secagem Convencional. Scientia Forestalis, Piracicaba, 36(80): 279-284.

Kollmann, F.E.P., 1959. Tecnologia de la Madeira e Sus Aplicaciones. Madrid: Gráficas Reunidas S.A.

Kollmann, F.E.P., W.A. Côte Junior, 1968. Principles of Wood Science and Technology. New York: Springer-Verlarg.

Lima, I.L., S.M.B. Florsheim, E.L. Longui, 2009. Influência do Espaçamento em Algumas Propriedades Físicas da Madeira de *Tectona grandis* Linn. Cerne, Lavras, 15: 244-250.

Lopes, C.S.D., A.M. Nolasco, Tomazello M. Filho, C.T.S. Dias, A. Pansini, 2011. Estudo da Massa Específica e da Variação Dimensional da Madeira de Três Espécies de Eucalipto Para a Indústria Moveleira. Ciência Florestal, Santa Maria, 21: 315-322.

Lumley, T.G., E.T. Choong, 1981. Solar Drying of Wood in Louisiana. Baton Rouge: Louisiana State University and Agricultural and Mechanical College.

Mendes, A.S., 1985. Utilização de Coletor Solar Parabólico na Secagem da Madeira. Dissertação (Mestrado em Engenharia Florestal) – Universidade Federal do Paraná, Curitiba.

Motta, J.P., 2011. Propriedades Tecnológicas da Madeira de *Tectona grandis* l.f. Proveniente do Vale Do Rio Doce, Minas Gerais. Dissertação (Mestrado em Ciências Florestais), Universidade Federal do Espírito Santo.

Moya, R., D. Perez, 2008. Effect of Physical and Chemical Soil Properties on Physical Wood Characteristics of *Tectona grandis* Plantations in Costa Rica. Journal of Tropical Forest Science, 20(14): 147-155.

Olandoski, D.P., G.M. Bonduelle, A.B. Cunha, 1998. Os Custos da Má Qualidade na Secagem de Madeira em Estufa. In: ENEGEP, Niterói. Anais... Niterói: ABEPRO, 7p.

Oliveira, J.T.S., M. Tomazello Filho, N.C. Fiedler, 2010. Avaliação da Retratibilidade da Madeira de Sete Espécies de *Eucalyptus*. Revista Árvore, Viçosa, 34(5): 929-936.

Ono, A., 2006. Secador Solar de *Eucalyptus camaldulensis* de 40 mm de Espesor. Laboratorio Tecnológico Del Uruguay. Departamento de ProyectosForestales, Montevideo, Nota Técnica, 7: 1-10.

Ono, A., A. Venturino, 2006. Secador Solar Para Madera: Condiciones Operativas. Laboratorio Tecnológico Del Uruguay. Departamento de Proyectos Forestales, Montevideo, Nota Técnica, 5: 1-6.

Ono, A., A. Venturino, P. Cárdenas, R. Castro, 2006. Secado Solar Em Invierno de *Eucalyptus grandis*: Estúdio Comparativo Entre dos Sítios Ubicados al Norte y al Sur. Laboratorio Tecnológico Del Uruguay. Departamento de Proyectos Forestales, Montevideo, Nota Técnica, 11: 1-14.

Plumptre, R.A., 1979. Simple Solar Heated Timber Dryers: Design, Performance and Commercial Viability. Commonwealth Forestry Review, 58(4): 243-251.

Quartaroli, L., J. Kuritza, H. Rancatti, G.O. Machado, Hillig, É. (sd). Propriedades Físicas da Madeira de Bracatinga (*Mimosa scabrella* Bentham) de Ocorrência na Região de Irati, PR. In Anais do II Seminário de Atualização Florestal e XI Semana de Estudos Florestais, UNICENTRO, Paraná.

Read, W.R., A. Choda, P.I. Copper, 1974. A Solar Timber Kiln. Solar Energy, 15: 309-316.

Reuss, M., S.T. Benkert, A. Aeberhard, P. Martina, G. Raush, B.V. Rentzell, N. Sogari, 1997. Modelling and Experimental Investigation of a Pilot Plant for Wood Drying. Solar Energy, 59(4/6): 259-270.

Robbins, A.M., 1983. Solar Lumber Kilns: Design Ideas. New Mexico Energy Research and Development Institute, University of New Mexico.

Rocha, M.P., I. Tomaselli, 2001. Efeito do Modelo de Corte nas Dimensões de Madeira Serrada de *Eucalyptus grandis* e *Eucalyptus dunnii*. Floresta e Ambiente, Seropédica, 8(1): 94-103.

Rocha, M.P., I. Tomaselli, 2002. Efeito do Modelo de Desdobro na Qualidade da Madeira Serrada de *Eucalyptus grandis*e *Eucalyptus dunnii*. Cerne, Lavras, 8(2): 73-86.

Rodríguez, L.E.S., M.A.C. Cardeña, I.G. Ahumada, 2003. Diseño y Operación de Una Estufa Solar Para Secar Madera. Ingeniería Revista Académica, 7(3): 35-48.

Roque, R.M., V.A. Ledesma, 2006. Estudio del Efecto del Espaciamiento Sobre el Peso Específico Básico y Contracciones em Plantaciones de Teca (*Tectona grandis*L.f.) de 10 Años em Guanacaste, Costa Rica. Revista Forestal Mesoamericana Kurú, Costa Rica, 3(7): 1-11.

Santini, E.J., 1981. Secagem de Madeira Serrada em Estufa Solar e Sua Comparação Com os Métodos Convencionais. Dissertação (Mestrado em Engenharia Florestal), Universidade Federal do Paraná, Curitiba.

Sattar, M.A., 1993. Solar Drying of Timber - a Review. Holzals Roh und Werkst off, 51: 409-416.

Sharma, S.N., P. Nath, B.I. Bali, 1974. A Solar Timber Seasoning Kiln. Journal of the Timber. Development Association India, 18(2): 10-26.

Siau, J.F., 1995. Wood: influence of moisture on physical properties. Blacksburg: Virginia Polytechnic Institute and State University. Department of Wood Science and Forest Products.

Silva, J.R.M., L.M. Mendes, M.K. Wenzel, 1997. Secagem ao ar Livre da Madeira de *Eucalyptus grandis* Para a Produção de Móveis. Cerne, Lavras, 3(1): 170-186.

Simpson, W.T., 1991. Dry Kiln Operator's Manual. Madison: U.S. Department of Agriculture.

Souza, J.T., R. Trevisan, L. Denardi, D.M. Stangerlin, M.A. Vivian, C.R. Haselein, E.J. Santini, 2012. Qualidade da Madeira Serrada Proveniente de Árvores Dominantes e Médias de *Eucalyptus grandis* Submetidas à Secagem. Cerne, Lavras, 18(1): 167-174.

Stangerlin, D.M., R.R. Melo, E.J. Santini**,** S.A. Cordeiro**,** 2012. Comparação Econômica Entre os Métodos de Secagem de Madeira ao ar Livre e em Estufa Solar. Revista Brasileira Ciências Agrárias. Recife, 7: 850-856.

Steinmann, D.E., H.F. Vermaas, J.B. Forrer, 1980. Micro-Process or Control of a Solar Kiln. In: IUFRO Division V Conference, Wood drying papers, IUFRO, Oxford (Great Britain), pp: 71-96.

Stöhr, H.P., 1977. The Seasoning of South African Grown *Eucalyptus grandis* and *Eucalyptus saligna*. South African ForestryJournal, 102: 61-66.

Sturion, J.A., F. Silva, 1989. Caracterizacion de lamadera de bracatinga para energia. In: Salazar, R. (Ed.). Manejo y aprovechamiento de plantaciones forestales com especies de uso multiple: actas Reunion IUFRO, Guatemala, abril. Turrialba: CATIE, pp: 541-549.

Troxell, H.E., L.A. Muller, 1968. Solar Lumber Drying in the Central Rocky Mountain Region. Forest Products Journal, 18(1): 19-24.

Tschernitz, J.L., W.T. Simpson, 1985. Design for Lumber Dry Kiln Using Solar/Wood Energy in Tropical Latitudes. Forest Products Laboratory, United States Department of Agriculture– USDA, Madison, pp: 1-18.

Vermaas, H.F., 2000. A Rewiew of Drying Technology for Young Fast-grown Eucalypts. In: The future of *Eucalypts* for Wood Products. Launceston, Tasmania, Proceedings...Tasmania: IUFRO, pp: 225-237.

Viehbeck, P., 1999. Lo Básico Del Secado De Maderaconenergía Solar. Eschborn: GTZ - Gate.

Wengert, E.M., 1971. Improvements in Solar Dry Kiln Design. U.S. Forest Service, Research Note FPL - 0212.