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COMPUTER-AIDED PREDICTION OF TIMBER AIR PRE-DRYING TIMES AND COSTS*

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SYNOPSIS. Extremely different opinions are found on the cost-effectiveness of air pre--drying of timber in temperate climate. The objective of the paper was to present results of the two-year experiments on timber air pre-drying of two different species (e.g. oak and pine) and two different thicknesses, as well as different dates of the pre-drying start. The obtained results were used to derive empirical models describing the rate of moisture content change. The obtained models were used in the computer software to predict pre--drying time depending on a date of the start of the process, species, thickness, initial and final moisture content. The analysis was completed by estimation of costs of pre-drying with previously developed and tested procedure.

KEY WORDS: cost-effectiveness, drying rate, Scots pine, European beech

INTRODUCTION

Reduction of energy consumption, as well as utilization of renewable sources of energy are common objectives of the implementation of the environment friendly technologies. In the case of timber drying it usually opens a discussion on cost-effectiveness of air drying or pre-drying utilizing solar and wind energy. Unfortunately, in Poland there is observed clear withdrawal of air drying of timber. The situation is caused by the number of factors including among others shortage of current assets for financing production in progress, tendency for reduction production cycles, increasing kiln drying potential, as well as demands on drying quality, large amounts of cheap wood wastes available on the Polish market which can be easily converted into heat. Moreover, extremely different opinions exist on the economical profitability of timber air pre-drying in conditions of the Polish climate. The

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economical effects of pre-drying depend on the large number of variables, which are very often specific for a given country. Therefore, it makes almost impossible to utilize experiences obtained in other regions. It justifies a detailed analysis of cost-effectiveness of air pre-drying for local conditions. The analysis took into account:

– rates of timber moisture content changes in the temperate climate,
– prices of energy and costs of environment use (emission of pollutions),
– timber prices and costs of obtaining finances,
– costs of investment and kiln operation.

OBJECTIVE

The objective of the paper is to estimate costs of timber air pre-drying for conditions of the Polish climate and compare them to costs of kiln drying.

METHODS AND MATERIAL

In the case of the Polish climate it is not possible to obtain the final moisture content of timber which could correspond to the recommended moisture content levels of wood products in use. Therefore, the presented analysis consisted of

– green timber air pre-drying to the air-dried moisture content as compared to timber kiln drying for the same range of the moisture content change (i.e. green to air-dried moisture content),

– combined drying of green timber to the moisture content recommended for wood products in use, i.e. green timber air pre-drying followed by kiln drying.

The cost analysis of timber air pre-drying and kiln drying was made with the use of the method already developed by the authors and successfully applied for drying costs estimation in different conditions (Guzenda et al. 1998, Guzenda and Grzybowski 1999, Guzenda and Olek 2000, Olek et al. 2002). In order to obtain the objective of the present paper it was necessary to get a set of credible data on green timber pre-drying kinetics in the Polish climate as a function of time.

The set of pre-drying kinetics data had to be supplemented with values of the equilibrium moisture content varying among others with time. For short time intervals the equilibrium moisture content of wood depends on random changes of ambient air parameters. However, for longer time instants the randomness is significantly reduced and ambient air parameters start to be a function of a geographical position and a season. The values of the equilibrium moisture content can be determined from meteorological data given as mean monthly values of ambient air temperature and relative humidity. In this case the Hailwood-Horrobin model adapted for wood by Simpson (1973) was used to calculate mean monthly values of the equilibrium moisture content (Fig. 1). The obtained relationship can not properly describe possible variation of the values within individual months. Therefore, it was decided to determine the equilibrium moisture content variation

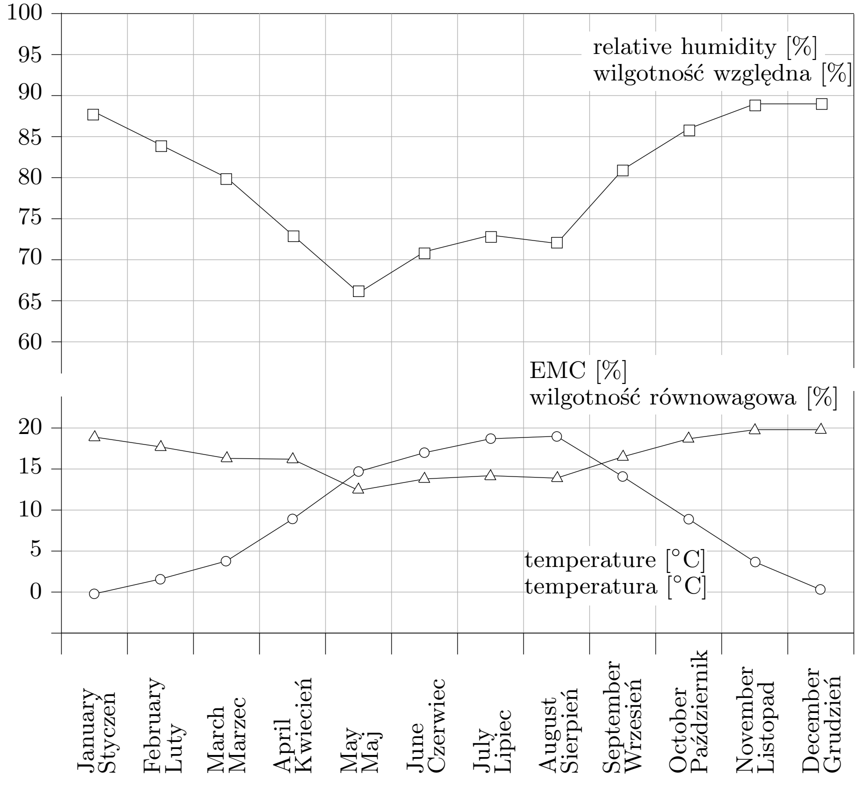

Fig. 1. Mean monthly values of ambient air parameters in Poznań, Poland (source: WetterOnline 2004) together with calculated equilibrium moisture content values

Rys. 1. Średnie miesięczne wartości parametrów powietrza otoczenia w Poznaniu, Polska (źródło: WetterOnline 2004) wraz z obliczonymi wartościami wilgotności równowagowych

using veneer samples exposed to changes of parameters of ambient air. The results of the experiment are presented in Figure 2.

The investigations of pre-drying kinetics were performed for two species of timber, i.e. Scots pine (*Pinus sylvestris* L.) and European beech (*Fagus sylvatica* L.). For the both species boards of thickness of 25 and 50 mm were cut from green timber. The end faces of boards were sealed in order to prevent moisture loss. Every month a new portion of boards was placed in a specially constructed pile covered with a roof. The construction of the pile let to add new boards without any change of the pile geometry. During two years of the experiment each board was weighed once a week. The oven-dry mass of boards was determined on the end of the experiment. The pre-drying kinetics was described by the rate of moisture content changes (g) defined as:

$$g = \frac{\Delta MC}{\Delta \tau};\ \%/\text{day} \qquad (1)$$

where ΔMC is moisture content change in time $\Delta \tau$. The values of the rate (g)

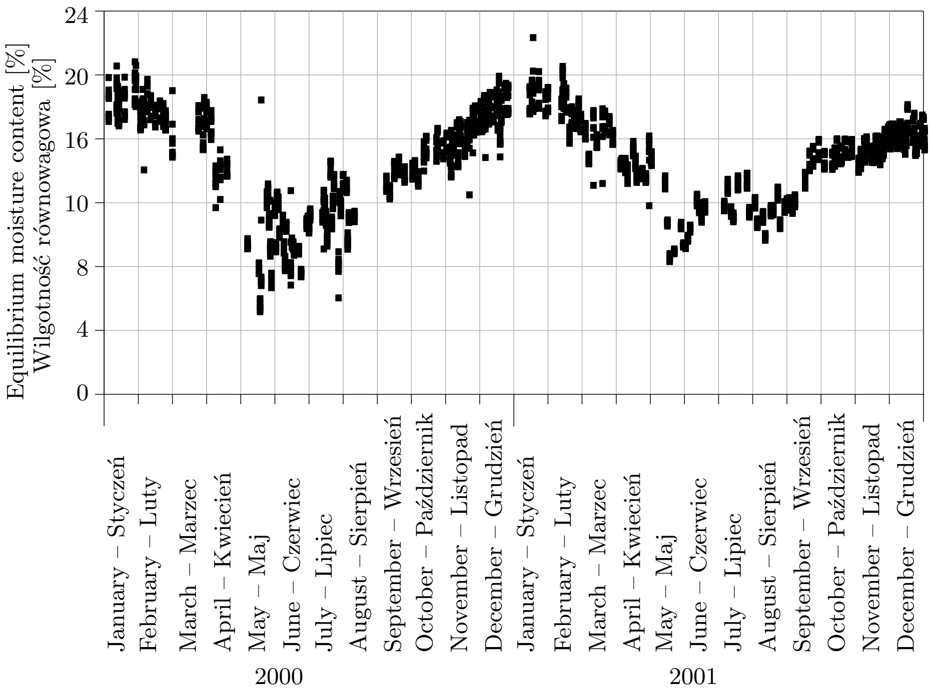

Fig. 2. Experimentally determined equilibrium moisture content for outdoor conditions in 2000 and 2001 in Poznań, Poland
Rys. 2. Doświadczalnie określone wartości wilgotności równowagowej dla warunków otoczenia w latach 2000 i 2001 w Poznaniu, Polska

were separately determined for both species and thicknesses in the following ranges of moisture content change:

– green moisture content to Fiber Saturation Point,
– Fiber Saturation Point to 20%.

RESULTS

The values of the rate of moisture content changes (g) for the 50 mm thick timber as a function of time are presented in Figures 3 and 4 (the analogous results for the 25 mm thick timber are not presented here due to the limitations of the paper). In the initial stage of pre-drying there were observed differences in the moisture content decrease of the both analyzed species. The rate g was always higher for Scots pine as compared to European oak. The lack of the distinct pre-drying effects was found in winter for moisture contents lower than 25% for Scots pine (Fig. 3) and lower than 40% for European oak (Fig. 4). Despite of that, timber of the both species obtained the final moisture content close to the equilibrium moisture content at the end of the experiment. In the case of oak timber it was

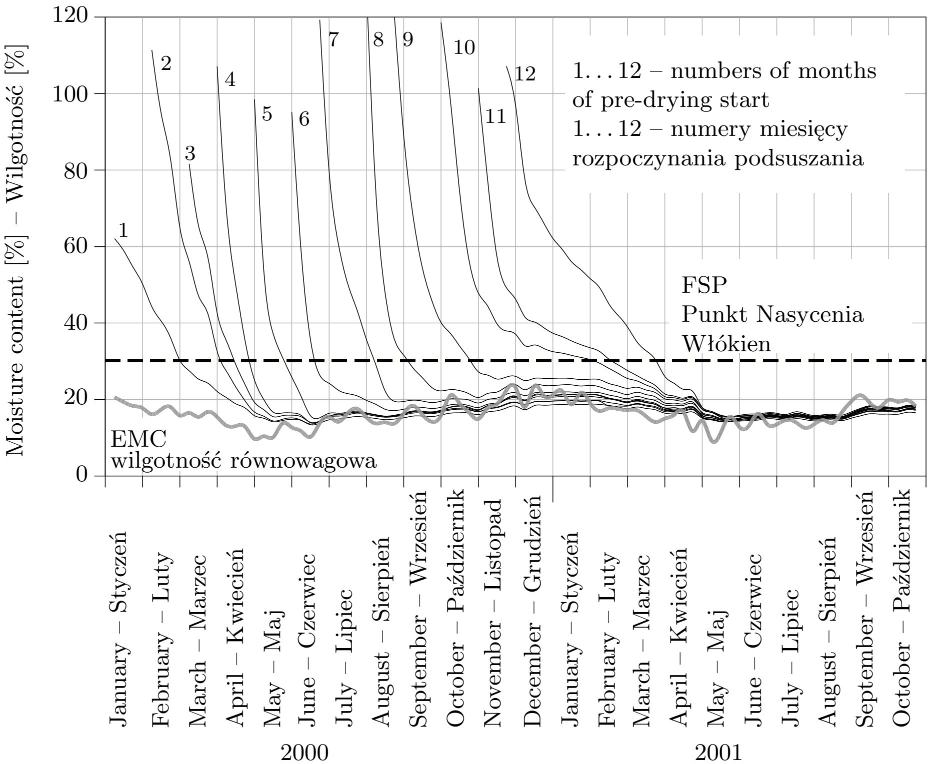

Fig. 3. Moisture content changes of 50 mm thick Scots pine timber
Rys. 3. Zmiany wilgotności tarcicy sosnowej o grubości 50 mm

primary due to the effect of the equilibrium moisture content increase caused by the change of ambient air parameters in the final stage of the experiment (Fig. 4).

The values of the rate of moisture content changes (g) for each month of the experiment are presented in Table 1. The negative values of g show the opposite process to pre-drying, i.e. moisture absorption in autumn and winter by timber which was effectively pre-dried in summer. The obtained values of the rate of moisture content changes were approximated with an empirical model of the form:

$$g = a_0 + a_1 \cdot \tau + a_2 \cdot \tau^2 + a_3 \cdot \tau^3 + a_4 \cdot \tau^4; \ \%/\text{day} \qquad (2)$$

where $a_0 \ldots a_4$ – coefficients of the model, τ – time. The coefficients of the empirical model obtained for both species are presented in Table 2 for the following changes of moisture content, i.e. from green moisture content to Fiber Saturation Point and from Fiber Saturation Point to 20%, respectively. The values of g obtained from the experiment as well as their representation with the estimated empirical model are presented in Figures 5 and 6. The obtained empirical model was input into the computer program of the cost analysis. It let to determine pre-drying times of timber of the arbitrary initial moisture content and the assumed final moisture content as a function of a date of starting the process. Therefore, the basic parameter of costs analysis was established.

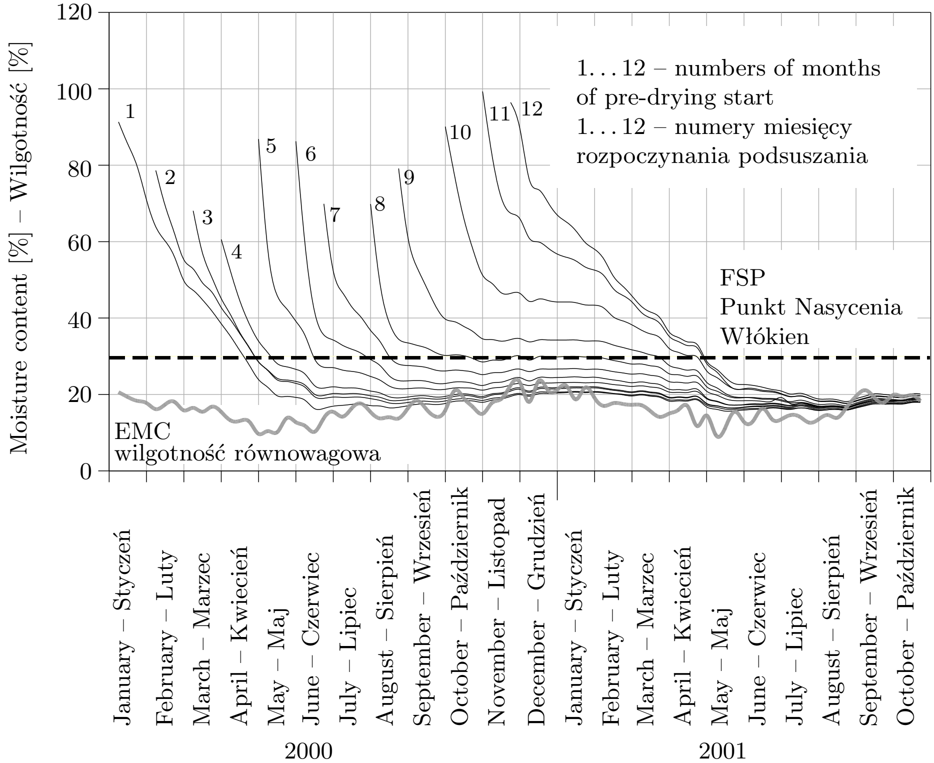

Fig. 4. Moisture content changes of 50 mm thick European oak timber
Rys. 4. Zmiany wilgotności tarcicy dębowej o grubości 50 mm

Table 1. Mean monthly values of the rate of moisture content change g; %/day for successive months. 50 mm thick timber
Tabela 1. Średnie miesięczne wartości strumienia zmian wilgotności dla poszczególnych miesięcy. Tarcica o grubości 50 mm

Month – Miesiąc	Scots pine – Sosna		European oak – Dąb	
	Green MC – 30% wilgotność świeżo po ścięciu – 30%	30-20%	Green MC – 30% wilgotność świeżo po ścięciu – 30%	30-20%
January – Styczeń	0.408	0.001	0.415	−0.004
February – Luty	0.996	0.099	0.945	0.037
March – Marzec	0.759	0.194	0.362	0.051
April – Kwiecień	1.626	0.390	0.527	0.094
May – Maj	3.213	0.832	0.563	0.194
June – Czerwiec	3.074	0.585	0.771	0.115
July – Lipiec	2.388	0.188	0.405	0.050
August – Sierpień	2.161	0.458	0.446	0.111
September – Wrzesień	1.434	0.310	0.378	0.030
October – Październik	1.537	0.224	0.450	0.024
November – Listopad	1.626	−0.850	0.312	−0.161
December – Grudzień	0.720	−0.023	0.215	−0.018

Table 2. Estimated coefficients of the empirical model, Eq. (2) representing the rate of moisture content changes during pre-drying of 50 mm thick timber
Tabela 2. Estymowane wartości współczynników modelu empirycznego (równanie 2) reprezentującego strumień zmian wilgotności w czasie podsuszania tarcicy o grubości 50 mm

Species Gatunek drewna	Moisture content Wilgotność [%]	Coefficients of the empirical model Współczynniki modelu empirycznego				
		a_0	a_1	a_2	a_3	a_4
Scots pine	>30	0.5703	−0.5604	0.4341	−0.0619	0.0025
Sosna	30-20	0.0662	−0.1953	0.1425	−0.0211	0.0009
European oak	>30	0.4542	−0.1089	0.0557	−0.0075	0.0003
Dąb	30-20	0.0266	−0.0591	0.0395	−0.0059	0.0002

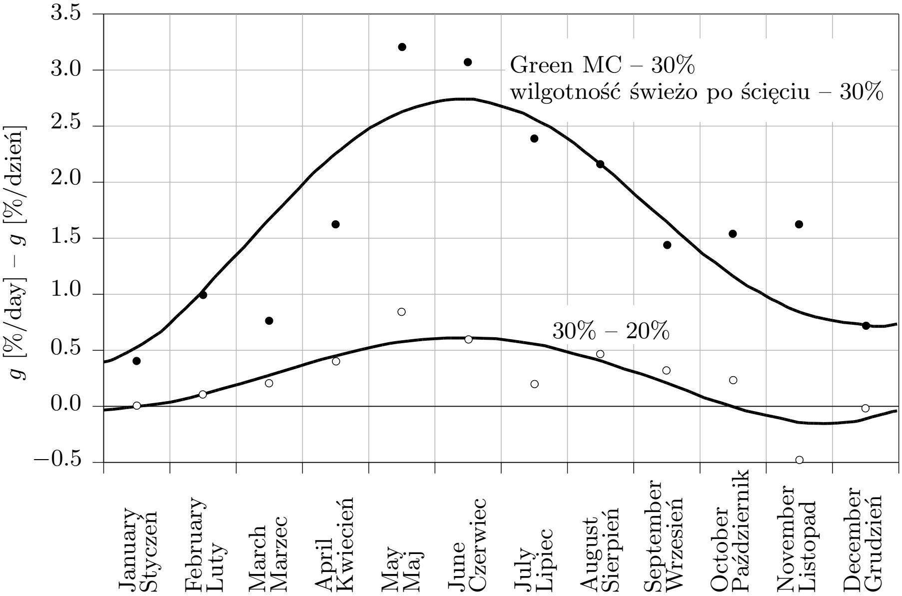

Fig. 5. Approximated by the model and experimental mean monthly values of the rate of moisture content change (g) of 50 mm thick Scots pine timber
Rys. 5. Aproksymowane przez model oraz zmierzone średnie miesięczne wartości strumienia zmian wilgotności (g) tarcicy sosnowej o grubości 50 mm

The predicted in the analysis costs of air pre-drying and kiln drying can be expressed in absolute values, i.e. in Polish zloty (PLN) or Euros. Such a representation of the costs is susceptible to variation of exchange rates and inflation. Therefore, it is very difficult to perform a credible comparison analysis of the costs in longer time periods especially in the case of processes performed in different climates and economic conditions. It inclined us to make the analysis for costs transferred into relative values.

The results of the analysis are presented for two sets of drying processes. The first set represents air pre-drying of green timber to the final moisture content

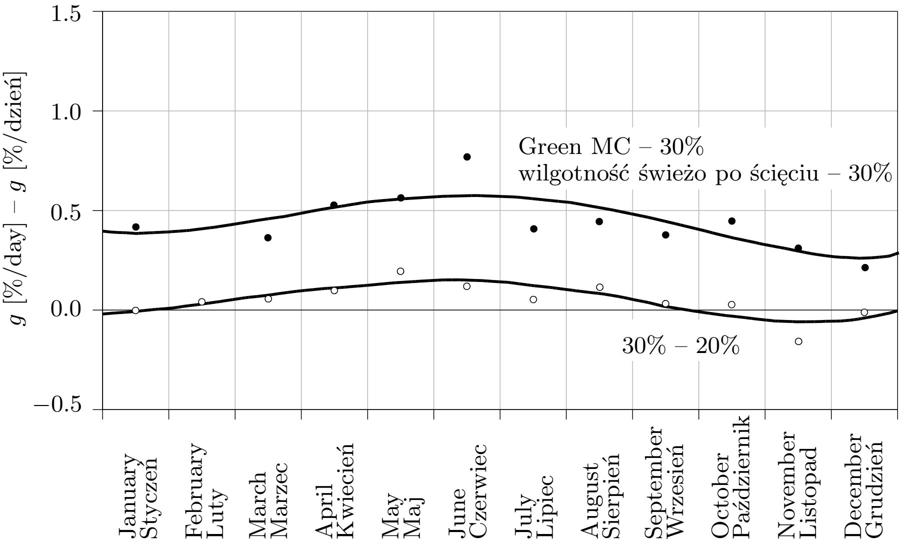

Fig. 6. Approximated by the model and experimental mean monthly values of the rate of moisture content change (g) of 50 mm thick European oak timber
Rys. 6. Aproksymowane przez model oraz zmierzone średnie miesięczne wartości strumienia zmian wilgotności (g) tarcicy dębowej o grubości 50 mm

of 30% as well as kiln drying for the same change of moisture content. The second set consists of green timber pre-drying to moisture content of 30% followed by kiln drying to the final moisture content of 8% as well as kiln drying from green moisture content to the final moisture content of 8%. The prices of green timber were expressed in Polish currency (PLN) and recalculated into Euro (€) with the exchange rate of 1 € = 4.75 PLN getting 600 PLN/m^3 (126 €/m^3) for Scots pine and 1500 PLN/m^3 (316 €/m^3) for European oak. Kiln drying costs were calculated for kiln net load capacity of 44 m^3 for 25 mm thick timber and 58 m^3 for 50 mm thick timber. Air velocity was assumed as equal to 2 m/s. Kiln drying times and components of costs were collected in industrial conditions.

The results of the analysis performed for green timber air pre-drying to moisture content of 30% as well as kiln drying for the same change of moisture content are presented in Table 3. The results were supplemented by dates of starting timber pre-drying in order to obtain the shortest and the longest pre-drying times. The obtained pre-drying costs were related to the kiln drying costs. There are observed high differences in pre-drying times of Scots pine of both thicknesses for processes starting in spring and autumn. For 50 mm thick Scots pine pre-drying which started at the turn of May and June the ratio of pre-drying costs to kiln drying costs was equal to 8.6%. The ratio increased to 57.1% for pre-drying starting in September. Pre-drying of 50 mm thick European oak which started in July generates costs which are almost as high as costs of green timber kiln drying to moisture content of 30%.

The results of the analysis of the combined drying of green timber to the final moisture content of 8% as well as green timber kiln drying to the same final moisture content are presented in Table 4. It was found that in the case of processes started in autumn costs of combined drying of both species and thicknesses are similar to costs of kiln drying only. It challenges the idea of air pre-drying preceding kiln drying for conditions of the temperate climate. The relation of the costs is only somewhat better for air pre-drying starting in spring.

FINAL REMARKS

The existing opinions on low cost-effectiveness of timber air pre-drying in Poland can be partially supported by the results obtained in the analysis. The low effectiveness of pre-drying in Poland is caused by high costs of financing production in progress, law prices of fuels (e.g. cheap coal) as well as unfavorable weather conditions in autumn and winter and therefore, generating long times of pre-drying (Table 3). The economical effect of pre-drying decreases with in-

Table 3. Ratio of pre-drying to kiln drying costs
Tabela 3. Stosunek kosztów podsuszania do kosztów suszenia w suszarkach

Species and thickness Gatunek i grubość drewna	Date of pre-drying start Data rozpoczęcia podsuszania	Pre-drying duration Czas podsuszania [days – dni]	Ratio of pre-drying costs to kiln drying costs Stosunek kosztów podsuszania do kosztów suszenia w suszarkach [%]
Scots pine 25 mm thick Sosna grubość 25 mm	2nd week of June (+) 2 tydzień czerwca (+)	21	5.5
	3rd week of October (–) 3 tydzień października (–)	158	42.7
Scots pine 50 mm thick Sosna grubość 50 mm	2nd week of June (+) 2 tydzień czerwca	38	8.6
	1st week of September (–) 1 tydzień września (–)	240	57.1
European oak 25 mm thick Dąb grubość 25 mm	1st week of May (+) 1 tydzień maja (+)	75	26.6
	1st week of October (–) 1 tydzień października (–)	180	62.9
European oak 50 mm thick Dąb grubość 50 mm	1st week of March (+) 1 tydzień marca (+)	202	58.4
	3rd week of July (–) 3 tydzień lipca (–)	285	79.8

(+) denotes the best date for pre-drying start, (–) denotes the worst date for pre--drying start.

(+) oznacza najkorzystniejszą datę rozpoczynania podsuszania, (–) oznacza najmniej korzystną datę rozpoczynania podsuszania.

Table 4. Ratio of combined drying to kiln drying costs
Tabela 4. Stosunek kosztów łącznego suszenia do kosztów suszenia w suszarkach

Species and thickness Gatunek i grubość drewna	Date of pre-drying start Data rozpoczynania podsuszania	Ratio of combined process (pre-drying + kiln drying) to kiln drying costs Stosunek kosztów łącznego procesu (podsuszanie + suszenie w suszarkach) do kosztów suszenia w suszarkach [%]
Scots pine 25 mm thick Sosna grubość 25 mm	2nd week of June (+) 2 tydzień czerwca (+)	61.5
	3rd week of October (−) 3 tydzień października (−)	89.2
Scots pine 50 mm thick Sosna grubość 50 mm	2nd week of June (+) 2 tydzień czerwca (+)	63.4
	1st week of September (−) 1 tydzień września (−)	98.6
European oak 25 mm thick Dąb grubość 25 mm	1st week of May (+) 1 tydzień maja (+)	58.7
	1st week of October (−) 1 tydzień października (−)	80.9
European oak 50 mm thick Dąb grubość 50 mm	1st week of March (+) 1 tydzień marca (+)	69.2
	3rd week of July (−) 3 tydzień lipca (−)	81.3

(+) denotes the best date for pre-drying start, (−) denotes the worst date for pre--drying start.

(+) oznacza najkorzystniejszą datę rozpoczynania podsuszania, (−) oznacza najmniej korzystną datę rozpoczynania podsuszania.

creasing timber thickness as well as decreasing initial and final moisture contents of timber. The combined drying is practically ineffective from the economical point of view and especially for the processes starting in autumn and winter it should be replaced with kiln drying. The computer program constructed for costs analysis can assist decision making processes in companies and indicate the best strategy of timber drying, i.e. starting the process with air pre-drying or with kiln drying.

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KOMPUTEROWO WSPOMAGANE PROGNOZOWANIE CZASÓW ORAZ KOSZTÓW PODSUSZANIA DREWNA

Streszczenie

Istnieją bardzo zróżnicowane opinie dotyczące ekonomicznej efektywności podsuszania drewna w warunkach klimatu umiarkowanego. Celem pracy było zaprezentowanie wyników dwuletnich eksperymentów podsuszania tarcicy dwóch różnych gatunków drewna (dębu oraz sosny) o dwóch różnych grubościach dla różnych terminów rozpoczynania podsuszania. Otrzymane wyniki wykorzystano do otrzymania empirycznych zależności opisujących szybkość zmian wilgotności. Uzyskane modele zastosowano w programie komputerowym prognozującym czas podsuszania w zależności od daty rozpoczęcia procesu, gatunku drewna, grubości, początkowej i końcowej wilgotności. Analiza została uzupełniona przez określenie kosztów podsuszania z wykorzystaniem wcześniej opracowanych i przetestowanych procedur.

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