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# Dynamic Appearances and Effects of Heat Source at Sawn Timber Drying

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Preliminary notes

High costs, irrational consumption of thermal energy and low efficiency are often characteristics of sawn timber drying by warm humid air in chamber drying kilns. A weak link between technological planning with the sawn timber mass dynamics in the systems with more drying kilns is the most common reason that influences considerably the economy of timber thermal processing and the heat source pre-dimensioning. Lack of experimental research and usage of general relations are common reasons for insufficient practical compliance and connection of drying thermal needs and the heat source capacity. Air heater thermal load has been researched during the sawn oak timber drying, 25 mm thick, as well as 32 mm and 50 mm thick beech, by applying of appropriate regimes during all the stages in more cycles of convective drying. Current thermal needs have been measured and registered in relation to maximal values during the characteristic intervals of each drying cycle. The exact values have been shown, while the defined correlation polynome has been used to describe a graphic and mathematical model of thermal load in all intervals of tested sawn timber drying cycles. An analytical procedure for determination of total maximal thermal needs of more drying kilns has been suggested based on timber moisture decreasing and technological drying planning. Using a characteristic example, its applicability and contribution to an optimal thermal source dimensioning has been shown.

**Keywords**

*Drying kiln*
*Sawn timber*
*Thermal load*
*Drying dynamics*
*Regression polynome*
*Planning*
*Heat source*

**Dinamičke pojave i učinak izvora topline kod sušenja piljenog drva**

Prethodno priopćenje

Viši troškovi, neracionalna potrošnja toplinske energije i mala učinkovitost česte su značajke sušenja piljenog drva toplim vlažnim zrakom u komornim sušarama. Slaba povezanost tehnološkog planiranja s dinamikom sušenja piljene drvne mase u sustavima s više sušara najčešće značajno utječe na ekonomičnost toplinske obrade drva i predimenzioniranje izvora topline. Nedostatak eksperimentalnih istraživanja i korištenjem općih relacija česti su razlozi nedovoljne praktične usklađenosti i povezanosti toplinskih potreba sušenja i kapaciteta izvora topline. Provedena su istraživanja toplinskog opterećenja grijača zraka pri sušenju piljenog drva hrasta debljine 25 mm te bukve debljine 32 mm i 50 mm, primjenom odgovarajućih režima tijekom svih faza u više ciklusa konvektivnog sušenja. Izmjerene su i registrirane trenutne toplinske potrebe u odnosu na maksimalne vrijednosti tijekom karakterističnih intervala svakog ciklusa sušenja. Prikazane su egzaktne vrijednosti, a pridruženim korelacijskim polinomom opisan je grafički i matematički model toplinskog opterećenja u svim intervalima ispitivanih ciklusa sušenja piljenog drva. Predložen je analitički postupak za određivanje ukupnih maksimalnih toplinskih potreba više sušara na osnovi dinamike snižavanja vlage drva i tehnološkog planiranja sušenja. Karakterističnim primjerom je prikazana njegova primjenjivost i doprinos optimalnom dimenzioniranju izvora topline

**Ključne riječi**

*Sušara*
*Piljeno drvo*
*Toplinsko opterećenje*
*Dinamika sušenja*
*Polinom regresije*
*Planiranje*
*Izvor topline*

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## 1. Introduction

Artificial drying is an unavoidable technological process of sawn timber treatment and processing into final products. Correctly stacked humid sawn timber is dried in chamber kilns by forced circulation of warm humid air up to a relatively low final moisture share $u$. Variability of influential parameters (temperature, relative humidity and air flow speed) and their dependence on properties, condition, dimensions and final timber purpose require an application of appropriate regimes in all timber drying stages. Due to non-homogenous structure and complex physical processes of free and binding moisture extraction from the timber mass, various drying regimes are used, depending on a type, density, assortment and the beginning and final timber moisture [1,2,3]. By implementing an adjusted drying regime with a certain timber mass during each cycle, a variable quantity of thermal energy is used, having large differences from maximal to minimal values. In principle, during heating, initial air conditioning and removing of exceptionally rough moisture from the surface of extremely humid timber, most thermal energy is used. By gradual increasing the drying gradient and removing the part of free and binding moisture, the thermal energy consumption is, at first suddenly and then in hygroscopic area a bit slower, decreased up to its minimal value and at the end of drying with a low timber moisture share. A larger part of thermal energy is used on breaking hygroscopic links between cell walls and timber moisture, and a smaller part is used on moisture removing by circulating air through gaps between timber stacks. The removal of above-hygroscopic (rough) moisture in the first interval of drying cycle lasts for a very short period of time compared to the duration of other drying intervals (sometimes even more than ten times shorter), especially compared to the intervals of hygroscopic moisture removal from sawn timber mass until the drying end [4,5,6,7,8].

Thermal energy needs are often superficially estimated, especially when more drying kilns are built attached to each other, having approximately the same technical characteristics and filling capacity with correctly stacked sawn timber mass. Usually the total effect of the thermal source is determined by adding the maximal thermal effect of each attached drying kiln in a row to the common thermo-technical system, without technological planning and analysis of sawn timber drying dynamics, which influences the economy and efficiency of thermal timber processing.

## 2. Aim of research

The aim of research is measuring and monitoring of air heater thermal load in circulation during sawn oak and beech timber drying by applying of appropriate regimes during all the stages and cycles of drying, as well as evaluating of results from the rational and economy dimensioning of total thermal needs point of view. By applying synthesis of exact measurement and adjusted mathematical support, a special relation in determination of thermal source optimal thermal effect for more drying kilns is suggested, which is conditioned by the technological planning and the drying dynamics based on mean share of a hard timber moisture decrease.

## 3. Research objects, material and method

### 3.1. Object and material

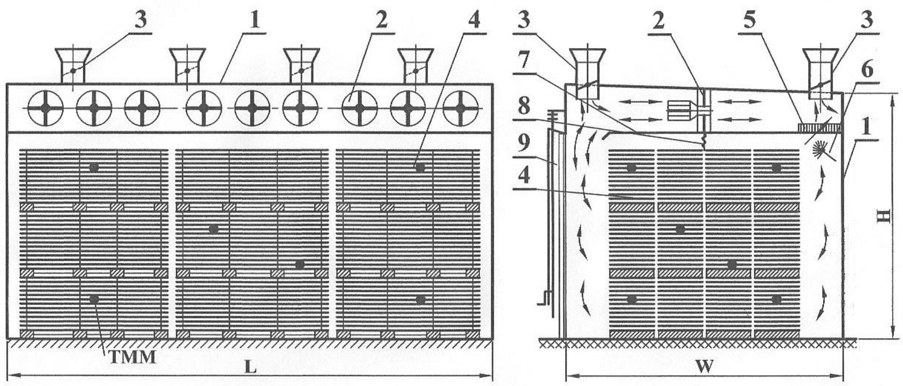
The tests were carried out in four serially connected chamber kilns of high thermal and regulated constructive stability [9]. The loading capacity of each drying kiln is from 100 $m^3$ up to 130 $m^3$, depending on the type, density and assortment of sawn timber. With the help of air laminated heaters having the maximal effect Q = 550 kW per drying kiln, the adjusted temperature of circulating humid air in all drying intervals was maintained until the final timber moisture share. The primary fuel medium is warm water with maximal temperature working regime of 90/70°C.

Exchanging of the part of circulating with fresh air and/or occasional high pressure spraying of small particles of water in the air flow, its relative humidity was maintained, which influences the speed of drying at certain temperature and the speed of air flow. With the help of nine reversible fans in each drying kiln, a continuous cycle circulation of humid air was carried out at changing speed, depending on current mean timber moisture $u$, i.e. the drying stage through gaps in timber stacks, Figure 1.

Experimental measurements were carried out by using the correctly stacked sawn timber, elements of oak being 25 mm thick and beech being 32 mm and 50 mm thick, at maximal chamber load capacity in each drying cycle. The dried sawn timber was used in the final parquets production and in single furniture elements. The experimental measurements were being carried out from September, 2008 until June, 2010 at various external microclimatic conditions in all periods and seasons of the year.

### 3.2. Research method

The processes of hard timber elements were carried out by a computer navigation, with a software support adjusted to the drying regimes: eleven cycles of 25 cm thick oak, one cycle of 32 mm thick beech and four cycles of 50 mm thick beech [10].The starting mean moisture of oak elements was between 60% and 90%, and in one cycle it was around 30%. Before the drying correctly stacked beech elements of 50 mm thickness their mean moisture had been between 65% and 90%, and in one drying cycle of elements 32 mm thick it had been around 25%. After the completed cycles the mean final share of moisture in dried elements for both types of hard wood/timber was around 8% and they were used in the final production. The drying regime was managed by ten pairs of penetrating electrodes put in characteristic places into the timber stacks (Figure 1) by measuring of electrical resistance at moisture share decreasing in the timber mass.




1 – insulated kiln's external walls and ceiling
2 – axial reversible fans
3 – fan's vents
4 – sawn wood/timber stacks
5 – laminated air heaters
6 – high-pressure air moisturising by water
7 – ceiling tin for air direction
8 – curtain
9 – sliding doors with a moving mechanism

TMM – Timber moisture measurement, L – length, W – width, H – height

**Figure 1.** Schematic overview of the kiln with sawn timber stacks (longitudinal and cross sections)

**Slika 1.** Shematski prikaz sušare sa slojevima piljenog drva (uzdužni i poprečni presjek)

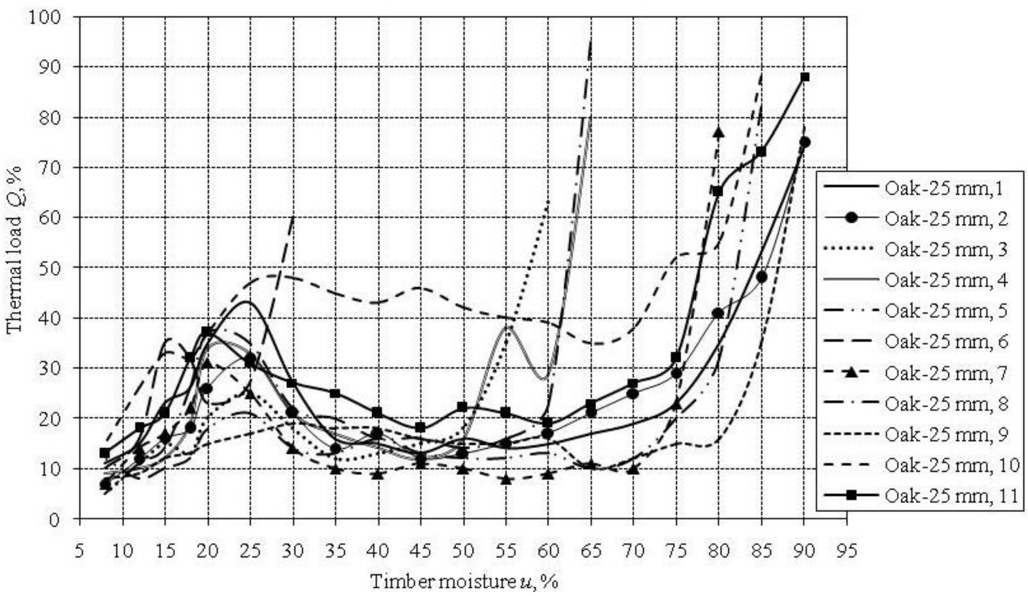



**Figure 2.** Thermal load at experimental drying of oak elements having thickness of 25 mm

**Slika 2.** Toplinsko opterećenje pri pokusnom sušenju elemenata hrasta debljine 25 mm

A continuous control and monitoring of influential parameters were carried out (temperature and speed of air flow, balancing moisture, air exchange,...) from the beginning until the end of each drying cycle. Apart from the range of regime measuring parameters, the data were continuously measured by comparison of values and relationships between the starting and the returning temperature of fuel medium as well as regulating valve plate movement and these data were transformed into the current percentage thermal effect of the air heater during each cycle in all drying intervals.

## 4. Measurement results

The air heater thermal load in relation to the decrease of the mean moisture value in timber by implementation of appropriate regime during each oak element drying is shown in the diagram in Figure 2, while the beech element is shown in Figure 3.

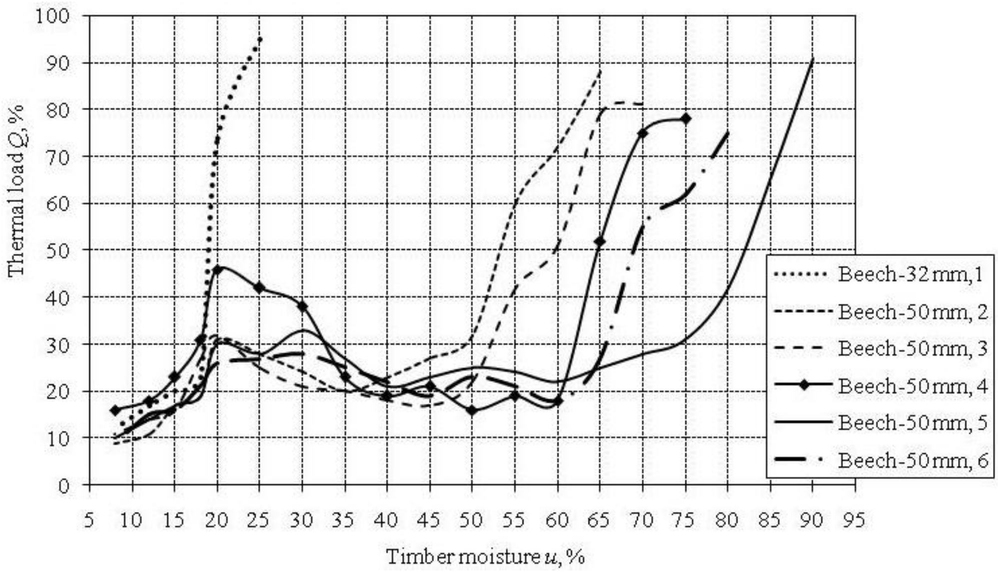



**Figure 3.** Thermal load at experimental drying of beech elements having thickness of 32 mm and 50 mm

**Slika 3.** Toplinsko opterećenje pri pokusnom sušenju elemenata bukve debljine 32 mm i 50 mm

Although a milder sharpness of drying regime, which is adjusted to a certain types, density and assortment of timber, is applied during heating and during removal of free moisture (around 95% up to around 60%), more thermal energy is used due to intensive circulation and exchange with fresh air at high relative air humidity in a kiln, which reaches maximal value, especially in unfavourable external microclimatic conditions (lower temperature and high relative air humidity). By lowering the mean value of timber moisture under 65% and by slower removal of remaining part of free moisture, considerably less thermal energy is used and the thermal load of air heater is between 10% and 25% of the maximal load. For feeding of heat and exctracting and moving of hygroscopic (binding) moisture from cell walls and its breaking through towards the timber surface, the thermal load of the air heater is around 20% up to around 35%, while at decresing of timber moisture is around 15% until the end of drying, the thermal load of the air heater is around 8 to 10 times lower than the maximal value and is between 12% and 10%.

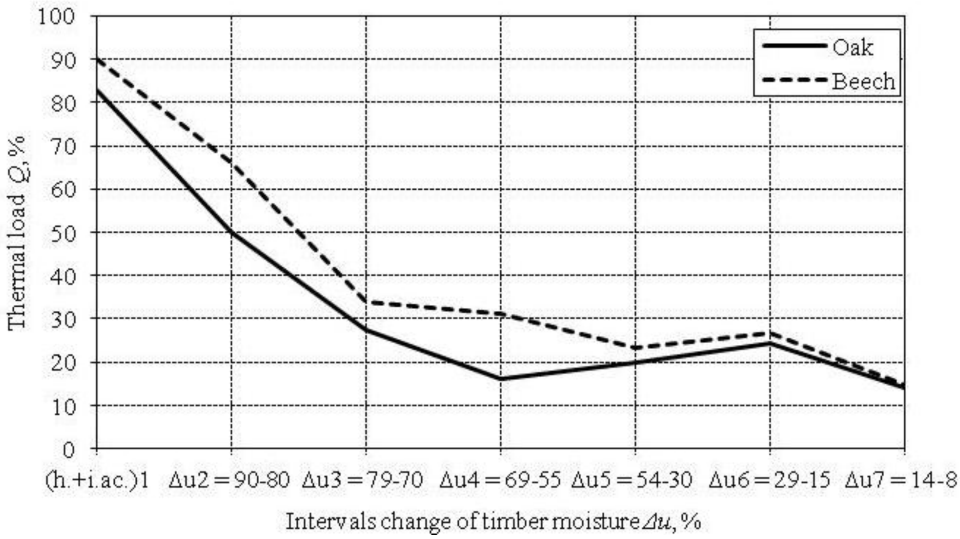



**Figure 4.** Mean thermal load during characteristic intervals timber drying (oak and beech elements)

**Slika 4.** Srednje toplinsko opterećenje tijekom karakterističnih intervala sušenja drva (elementi hrasta i bukve)

The curves in Figure 4 show mean values of the air heater thermal load for seven intervals of experimental beech elements drying cycles having 50 mm thickness and 25 mm thick oak, from high beginning mean share up to low final mean share of timber moisture. The decreasing mean share of timber moisture intervals $\Delta u$ are also the intervals of drying regime gradient adjusted to a certain timber type, density and assortment.

## 5. Result analysis

The cureves showing the mean values of thermal load for each kiln during seven characteristic intervals of experimental drying cycles of hard oak and beech timber are described best by a polynome interpolation. The variable approximation of thermal load change during a sawn timber drying cycle is decribed by a polynome function, according to the following relation:

$$Q(\Delta u) = \begin{cases} a_0 + a_1\Delta u + a_2\Delta u^2 + a_3\Delta u^3 + a_4\Delta u^4 + a_5\Delta u^5 & za \quad 1 < \Delta u < 7 \\ 0 & za \quad \Delta u < 1 \vee \Delta u \geq 7 \end{cases} . \quad (1)$$

**Table 1.** Polynome function coefficients of thermal load at sawn timber drying

**Tablica 1.** Koeficijenti polinomske funkcije toplinskog opterećenja pri sušenju piljenog drva

| Polynome function coefficients | Oak | Beech | Mean value (oak and beech) |
|---|---|---|---|
| $a_0$ | 80,4419 | 59,7429 | 86,1356 |
| $a_1$ | 39,7273 | 88,7652 | 33,3266 |
| $a_2$ | - 51,3604 | -78,1271 | - 44,5928 |
| $a_3$ | 15,5013 | 22,4529 | 13,1813 |
| $a_4$ | - 1,8336 | - 2,7233 | - 1,5207 |
| $a_5$ | 0,0748 | 0,1190 | 0,0601 |

Polynome coefficients $Q(\Delta u)$ are derived by Matlab function usage, which is based on the Simplex optimization method [11]. The function of the optimization method aim is the sum of square difference of experimental thermal load function and correlation polynome of the thermal load.

Table 1 shows individual coefficients and mean values of polynome function coefficients of thermal load at oak and beech sawn timber drying.

The percentage values of the air heater thermal load mean value $Q$ in the kiln during the experimental drying cycles and approximation of thermal load by correlation polynome are shown in the form of curves in Figure 5 for oak having thickness of 25 mm and in Figure 6 for beech having thickness of 50 mm.

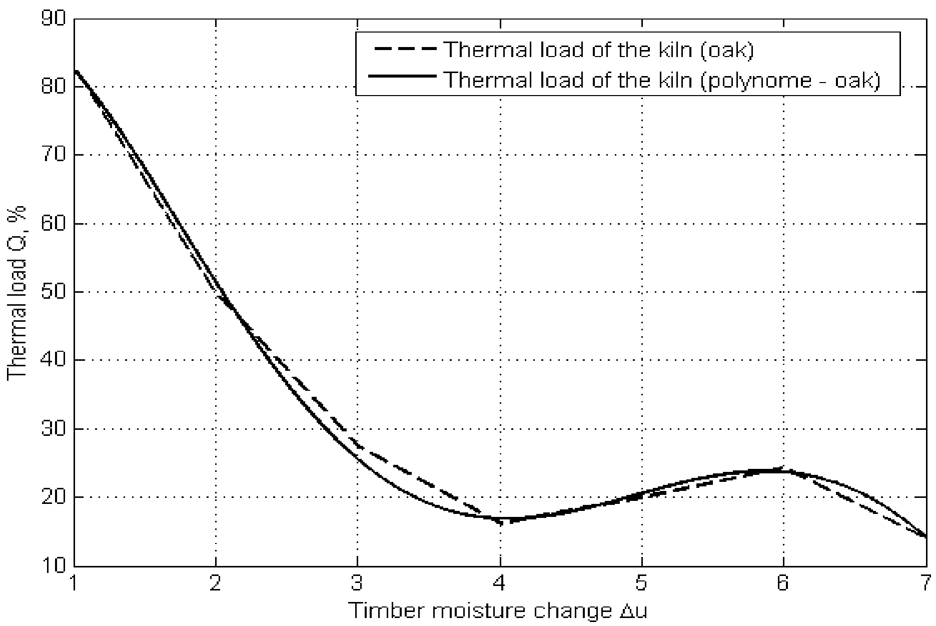



**Figure 5.** Thermal load depending on decreasing intervals of mean value of timber moisture (oak)

**Slika 5.** Toplinsko opterećenje ovisno o intervalima snižavanja srednje vlage drva (hrast)

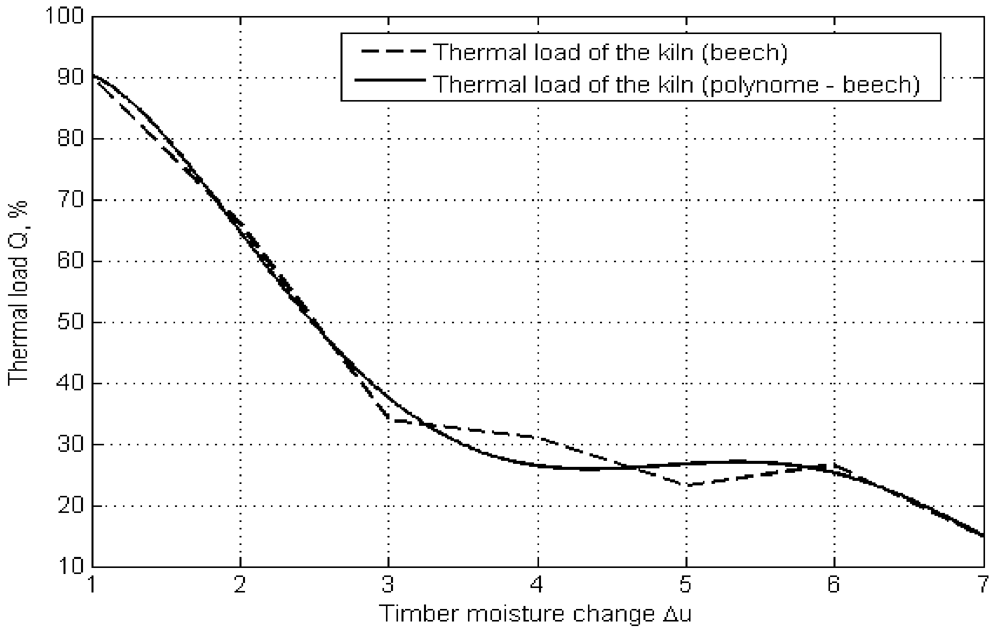



**Figure 6.** Thermal load depending on decreasing intervals of mean value of timber moisture (beech)

**Slika 6.** Toplinsko opterećenje ovisno o intervalima snižavanja srednje vlage drva (bukva)

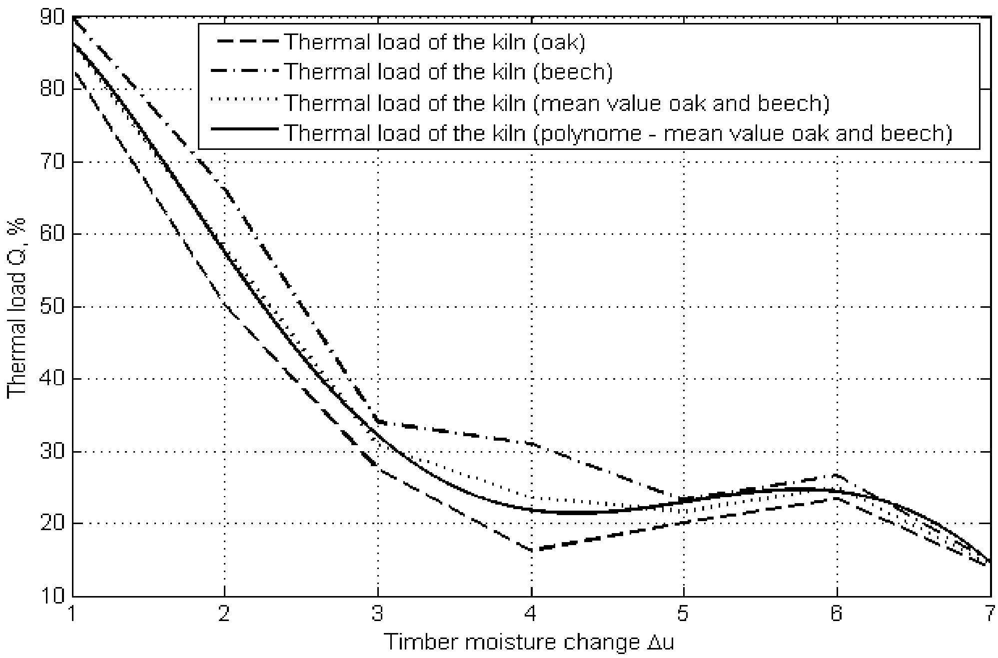



**Figure 7.** Thermal load depending on intervals of timber moisture mean value decrease (oak and beech)

**Slika 7.** Toplinsko opterećenje ovisno o intervalima snižavanja srednje vlage drva, srednja vrijednost (hrast i bukva)

The high compatibility of the air heater thermal load mean value perceby correlation polynome is shown in Figure 7.

Taking into account the function definition *Q(Δu),* the total thermal load of more kilns $Q_{\mathrm{total}}$ in a cycle work and their starting based on moisture decrease intervals *Δu* of sawn beech and oak wood/timber are shown in a diagram in Figure 8, by using the following relation:

$$Q_{total}(\Delta u) = \sum_{i=1}^{N} Q(\Delta u - i) \quad . \tag{2}$$

In the cycle work each next kiln starts its work after the end of the first interval of the previously started kiln. At the end of drying up to the final mean share of timber moisture and this kiln emptying, it is loaded with humid stacks of sawn timber and started in the first interval of drying of the previously started kiln. For a practically applicable row of six kilns of approximately same nominal thermal effect and loading capacity, the maximal thermal load $Q_{max}$ will be achieved while all the kilns work, at the moment when one of the kilns is started in the first drying interval of humid sawn timber (Figure 8), according to the relation:

$$Q_{max} = \sum_{\Delta u=1}^{6} Q(\Delta u) = 6a_0 + 21a_1 + 91a_2 + 441a_3 + 2275a_4 + 12201a_5 = 245,335\%; \quad (3)$$

for mean coefficient values of correlation polynome for oak and beech, $a_0$ to $a_5$.

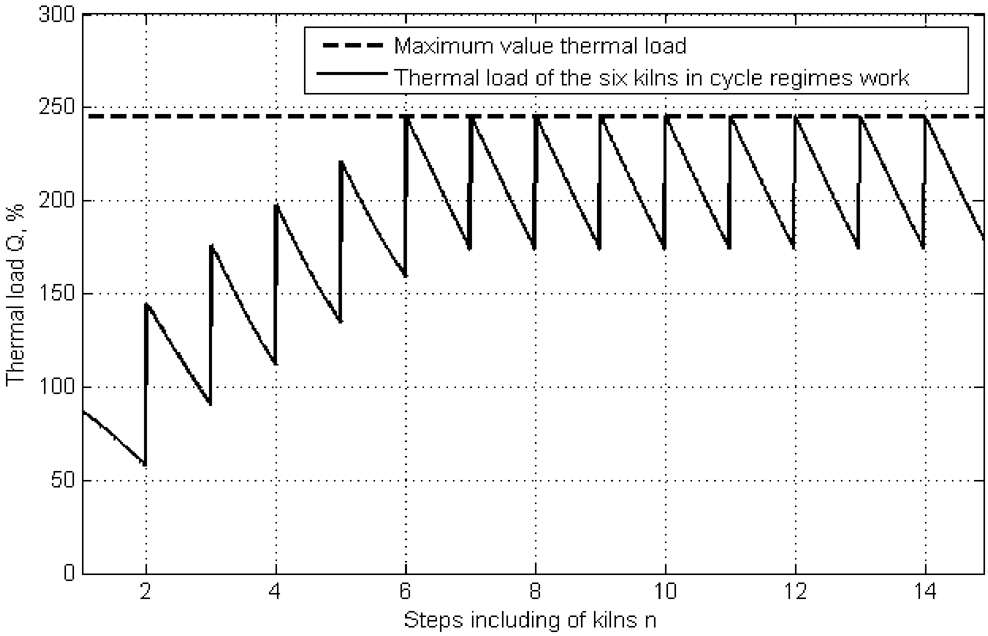



**Figure 8.** Thermal load of six kilns in cycle work

**Slika 8.** Toplinsko opterećenje šest sušara u cikličkom radu

values during seven characteristic intervals, from the beginning to the end of each drying cycle. The quantification diagrams show exact values, while the defind polynome function describes the graphic and

In relation to the simultaneous starting of all kilns and maximal thermal load (6 · 86,59% = 519,54%), planning and dynamics of sawn timber drying, the maximal thermal load is lower by 52,78%, which contributes to optimal dimensioning of heat source for heating, resulting in lower costs. The plant disturbances and/or discontinuity of drying processes may influence on the total heat source capacity increase or on making single stages of the sawn timber drying cycle longer.

## 6. Conclusion

The research has been carried out regarding the air heater thermal load at sawn oak and beech wood/timber drying, oak being 25 mm thick, and beech 32 mm and 50 mm thick, by applying appropriate regimes during all stages in more cycles of convective drying. Adjusted computer support and continuous measurement have registered current thermal needs in relation to maximal mathematical model of thermal load in all intervals of tested sawn timber drying cycles. An analytical procedure for determination of total maximal thermal needs for more kilns has been suggested based on the timber moisture decrease dynamics and the technological drying planning. Its applicability has been shown by a characteristic example, as well as its contribution to an optimal heat source dimensioning. The thermal source capacity is lower and higher efficiency and economy of the whole system is achieved.

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