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CHANGE IN THE WOOD MOISTURE DEPENDENCY ON TIME AND DRYING CONDITIONS FOR HEATING BY WOOD COMBUSTION

Horák Jiří, Kuboňová Lenka, Tomšejová Šárka, Laciok Vendula
Krpec Kamil, Hopan František, Kubesa Petr, Kysučan Zdeněk, Ochodek Tadeáš
Všb-Technical University of Ostrava, Energy Research Center
Ostrava – Poruba, Czech Republic

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ABSTRACT

The aim of this study was to determine the drying time of firewood under the climatic conditions of the Czech Republic to decrease the moisture content to an acceptable level for combustion (under 20%). The effects of log size, outdoor/indoor drying and wood species were evaluated.

KEYWORDS: Drying, wood moisture content, indoor, outdoor, rate of moisture content loss.

INTRODUCTION

The use of biomass for heating in small combustion plants is governed according to the state energy policy of the Czech Republic (Ministry of Industry and Trade 2013). For combustion in stoves, fireplaces or cookers, the most used renewable fuel is wood, both in pieces and in the form of pellets and briquettes. In 2009, around the world, the annual demand for biomass accounted for 10% of the total demand for primary energy (IEA 2011). An estimate of the year-to-year development of biomass consumption in Czech households shows that the consumption in 2011 was approximately 3.5 million tons of biomass (Ministry of Industry and Trade 2013). The Czech Republic is among the countries with a relatively high percentage of forested area. The forests represent approximately 35% of the territory of the Czech Republic, of which about two thirds represent coniferous trees (spruce - 52%, pine - 15%, fir - 8%), and one third represent deciduous trees(beech - 14%, oak - 4%) (Khestl 2013).

The demand for wood for heating considerably increases with the start of the heating season; however, the procurement of dry wood at a reasonable price is difficult. Usually, only wet - raw wood is available (Horák et al. 2012).

Wood burning is a significant source of emissions of fine particulate matter, black carbon and semivolatile organics. All burning processes and the subsequent levels of emissions are influenced by the wood quality. For residential heating, the moisture content is a key parameter. Wood moisture significantly influences the calorific value of fuel, which is the most important parameter that characterizes wood as a fuel. In general, wood is a fuel that burns, and the heat that we use for our needs (heating, cooking, and hot water) is released during this process. Fuel consists of combustible hydrocarbons (h), ash (A) and water (W). Fuel consists of five basic elements: C carbon, H_2 hydrogen, O_2 oxygen, N_2 nitrogen and S sulfur. The first three elements fundamentally affect the internal combustion process and contain the chemically bound energy. The latter two elements affect the production of the pollutants. The sulfur content in the wood is minimal, which is a great advantage compared to coal, because SO_2 emissions from wood combustion are negligible.

The wood weight can be divided according to their bulk density into light, medium and heavy (see Tab. 1). The density depends on the type of wood and on its moisture content (the bulk density also increases with increasing moisture).

The dry basic density of wood in most species ranges from 450 to 850 kg·m^{-3} (Krajnc 2015). With regard to the macroscopic structure of wood, white wood and core wood are distinguished. Woods with mature wood without a colour-coded core (e.g., linden, hornbeam and maple) are included in the white woods; the core species contain more tannins, resins, etc. (e.g., larch, poplar and ash) (Khestl 2013).

Tab: 1: The sorting of wood according to the bulk density (Khestl 2013).

Wood weight	Bulk density of dry matter kg·m^{-3}	Example of wood species
Light	up to 500	poplar, spruce, lime tree
Medium	500 – 700	larch, maple, birch, ash, oak, cherry
Heavy	above 700	hornbeam

With decreasing water and ash content, the fuel quality is improved, i.e., the fuel more easily and efficiently burns and contains more energy. With decreasing ash content, the emissions of the solid pollutants (dust) are reduced, and the demand for maintenance of the combustion device is reduced (Horák and Kubesa 2012). If the wood is totally dry, its calorific value (meaning the calorific value of the fuel; the ash is negligible; and its content is usually less than 1%) is approximately 18.5 MJ. kg^{-1} of fuel (from the data of accredited laboratory of Energy Research Center, VŠB-TU Ostrava). However, raw wood (freshly cut) contains a considerable amount of water. The water content is influenced by the tree species and the season in which the tree was cut (EN 844-1 1997). Previous studies also have mentioned that wet wood produces more CO, VOC (volatile organic compounds), PAHs (polyaromatic hydrocarbons), etc. (Nord-Larsen et al. 2011).

The average relative moisture in wood matter is after cutting down in dependency on wood type in the range 35-65% (Nosek and Holubčík 2016). The diagram in Fig. 1 shows that long-term storage of wood with a relative moisture content of 65% in air at a temperature of 20°C promotes an equilibrium wood moisture of 12 wt% (Dzurenda and Deliiski 2010). The drying time of the wood depends on the surrounding conditions and can be prolonged with increasing average air humidity. For example, during a rainy summer, the wood will take longer to dry as long as it is stored in a wet shady place (for example, near a mountain stream). For example, a study (Abbot et al. 1997) conducted in the South African Savannah showed that the wood reached the equilibrium point of moisture in approximately 4 weeks during a dry period.

Wood that is used for combustion in stoves or fireplaces should be satisfactorily dried so that a large amount of heat is not consumed to evaporate water. The well-known recommended wood moisture value for combustion is below 20 wt% (Horák and Kubesa 2012). Ideally, the moisture content should be less than 15 wt%. Dried wood contains more energy, and therefore, the consumption of dry wood is significantly lower compared to the consumption of wet wood.

The water contained in the fuel not only causes a reduction in the fuel calorific value but also causes the following:

- A reduction in the combustion temperature in the fireplace and a prolonged ignition time of fuel decreases the temperature in the combustion chamber, which leads to an increase in the amount of pollutants that arise from incomplete combustion,
- An increase in the volume of flue gas and hence an increase in the chimney loss, reduces the efficiency,
- An increase in the dew point of the flue gases depending on a higher flue gas moisture content can cause condensation of water, organic acids and tar in the chimney and heat exchange surfaces, thus shortening their service life.

An increase in the moisture during a 12-month storage period was observed in the study of Casal et al. (2010). It was concluded that open-air storage is not an effective solution for dry biomass.

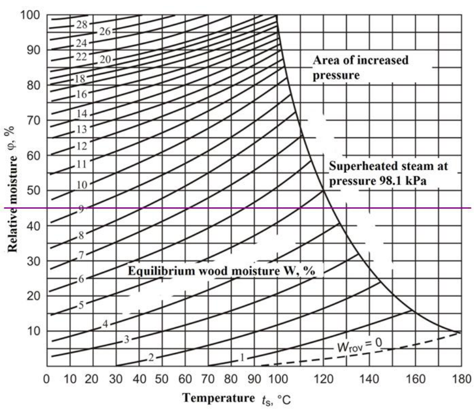

Fig. 1: The diagram of the steady moisture of wood (Dzurenda and Deliiski 2010).

The aim of this study is to determine the drying period of wood fuel in the Czech Republic to reduce the moisture content to an acceptable level of combustion, at least 20 wt%, depending on the type of wood, the shape of the wood and on the conditions of wood storage.

MATERIALS AND METHODS

Drying tests of wood were carried out in the period from March 2013 to February 2014 for ten different types of wood (see Tab. 2) both in the form of whole wood logs (representative diameter, approximately 14 cm and length, 30 cm) as well as the quarters of a wood log (length, 30 cm), see Fig. 2.

Fig. 2: a) A quarter of a log and b) the whole log.

The wood was tested at the Energy Research Center, VŠB - TU Ostrava. The individual forms of wood were dried outdoors under a shelter and in a sheltered, well-ventilated, unheated room. The individual types of wood were weighed before shelving and then at continuous intervals of approximately 20 days. The wood logs were weighed by the electronic balance (Kern type DE 12K1N) after equilibration with an accuracy of 0.001 kg.

Eq. 1 was used for the determination of wood moisture (Horák et al. 2012):

$$w_t = \frac{m_t - m_{105}}{m_t} \times 100 \qquad (1)$$

where: w_t - the moisture content of the total weight per time t (%),
m_t - the mass of the wood fuel,
m_{105} - the mass of dried wood at 105 °C.

At the end of the experiment, all logs were placed successively in a drying chamber and dried at 105°C to a constant weight with a specified moisture content value of 0.2% w/w. At least two samples of whole logs and 19 pieces of quarter logs (if available) were dried.

Tab. 2: Names and numbers of tested wood.

Type of wood	Whole wood log (pieces)	Quarter wood log (pieces)
Silver birch (*Betula pendula*)	4	19
Maple (*Acer*)	2	19
European larch (*Larix decidua*)	9	19
Littleleaf linden (*Tilia cordata*)	4	19
Wild cherry (*Prunus avium*)	4	19
Poplar (*Populus*)	x	19
European ash (*Fraxinus excelsior*)	x	19
European hornbeam (*Carpinus betulus*)	5	15
Norway spruce (*Picea abies*)	x	19
Sessile oak (*Quercus petraea*)	x	19
x…Sample of wood was not available		

The wood in a sheltered unheated room on wooden shelves was placed in a corner by the wall (see Fig. 3). Natural air circulated in the room. The room temperature and moisture content were recorded at 15-minute intervals.

The wood outside was deposited on the shelves by the wall with a rain shelter (Fig. 4). The monthly average air temperature and moisture content values for the Moravian-Silesian region, Czech Republic were delivered by the Czech Hydrometeorological Institute of Ostrava (see Tab. 3).

Fig. 3: The storage of wood inside.

Fig. 4: The storage of wood under a roof outside.

Tab. 3: Average values of precipitation and temperature in the year 2013 for the Moravian-Silesian region (Czech Hydrometeorological Institute 2018).

2013		Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Precipitation	mm	66	59	66	28	112	152	26	58	110	31	42	23
Temperature	°C	-3,2	-1,7	-1,4	7,8	12,3	15,7	18,7	17,8	11,0	9,5	4,4	1,4

RESULTS

The moisture loss progress of the individual types of wood in one year of drying are indicated in Figs. 5, 6, 7, and 8. The rate of wood drying is depicted (see Figs. 9, 10, 11, and 12). In our drying experiments, all conditions were optimal, and the drying rate was considered the maximum possible rate.

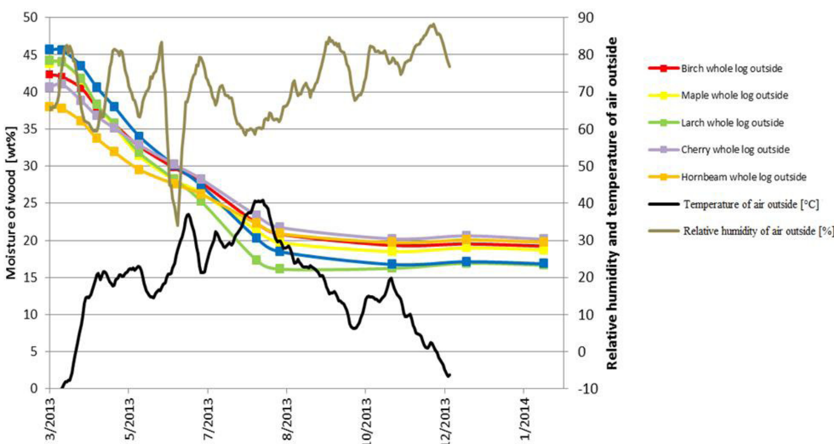

Fig. 5: The drying progress of the whole wood logs stored outside and the dependence on the wood type.

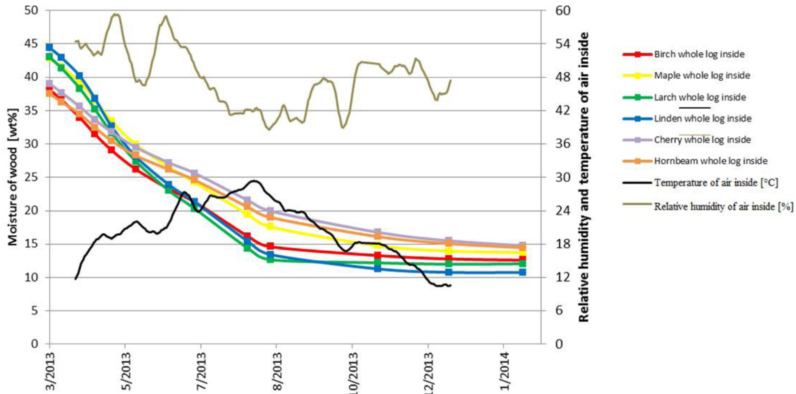

Fig. 6: The drying progress of the whole wood logs stored inside and the dependence on the wood type.

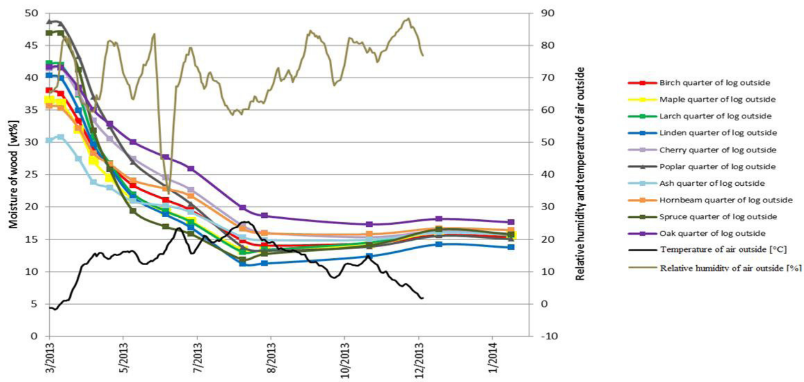

Fig. 7: The drying progress of the quarter wood logs stored outside and the dependence on the wood type.

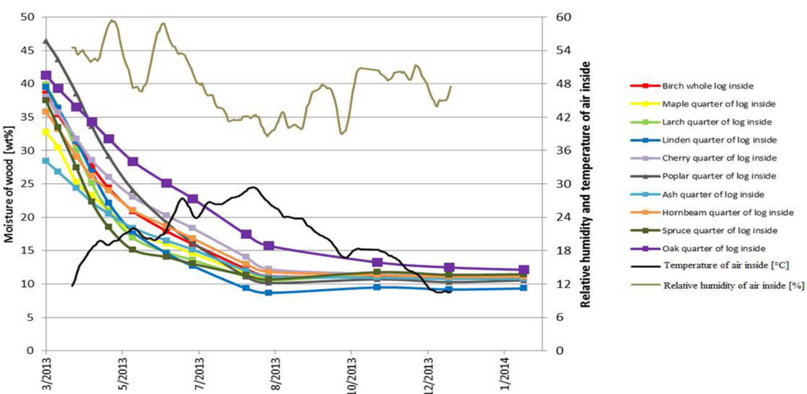

Fig. 8: The drying progress of the quarter wood logs stored inside and the dependence on the wood type.

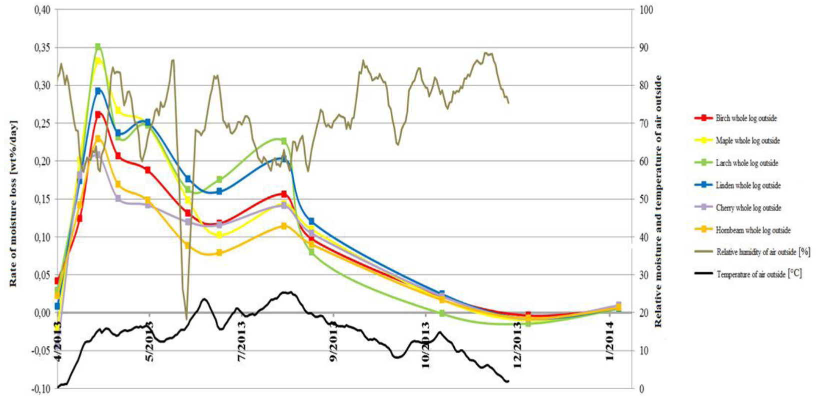

Fig. 9: Wood drying rates of the whole wood logs dried outside depending on the type of wood.

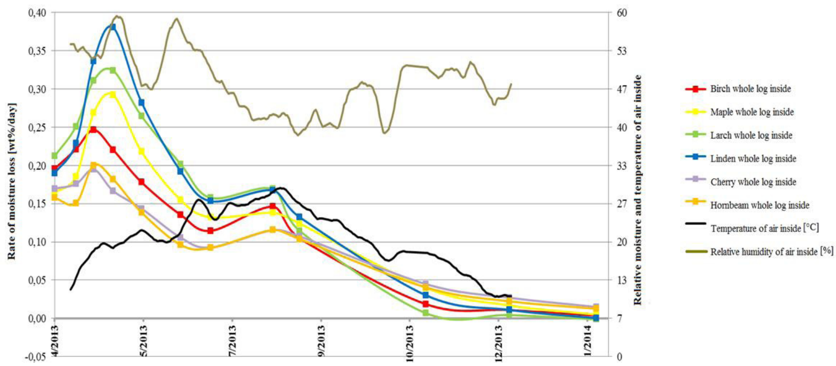

Fig. 10: Wood drying rates of the whole wood logs dried inside depending on the type of wood.

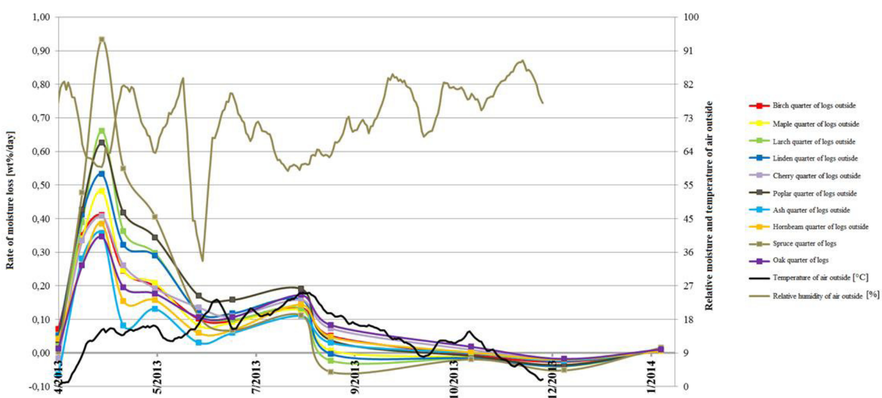

Fig. 11: Wood drying rates of the quarter wood logs dried outside depending on the type of wood.

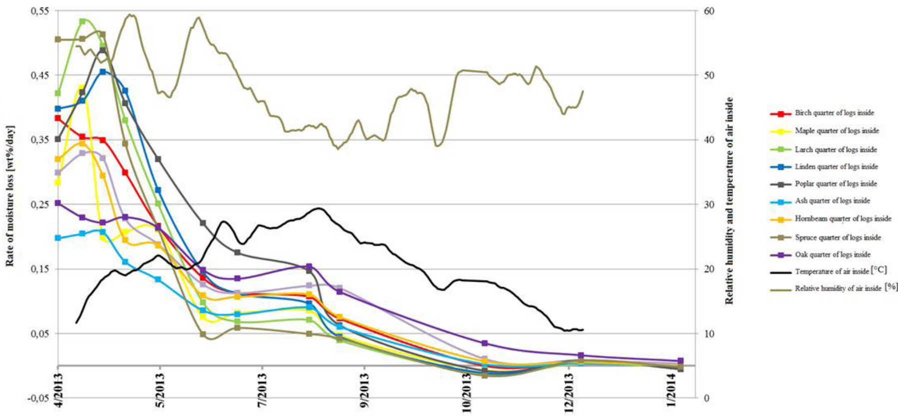

Fig. 12: Wood drying rates of the quarter wood logs dried inside depending on the type of wood.

The graphs show that moisture content in the whole wood logs at the end of drying reached 16-21 wt% in the outdoor environment and 11-15 wt% in the indoor environment. In the case of chopped wood logs (quarters of the logs), the moisture content was stabilized to 13-18% in the outdoor environment and 9-13% in the indoor environment. At the end of the drying process for the whole logs, the lowest moisture content was attained by linden as a representative light wood probably because of its highest initial moisture and the faster water diffusion through the more porous wood. The values were stabilized at 11 wt% in the indoor environment and 17 wt% in the outdoor environment. In the case of the chopped logs, the trend was the same; only the moisture content was lower by approximately 2-3 wt%.

Mathematical model

The aim was to describe the process of drying by mathematical model. The decrease in the moisture in the sample is determined (Eq. 2, modified Weibull distribution discovered by Rosin, Rammler, Sperling and Bennett (Stoyan 2013)):

$$w = w_0 \cdot \exp[-(\frac{t}{\tau})^{\beta}] \qquad (2)$$

where: w - the decrease in the moisture in the original sample (%),
w_0 - the initial state of moisture (%),
t - the drying time [days],
τ - the drying time of the decrease in the moisture of 63.2 (days),
β - sets process of drying.

The value w_0 is the constant, t is the x-value while the constant τ and β are appointed values according to modelling of curve with the experimental data points. The constants for all types of drying conditions are summarized in Tab. 4.

Eq. 2 does not describe the physical process of drying but describes the experimental observations. The model (Fig. 13) was applied for the experimental data of Fig. 5. The model is valid up to the point of 146 days of the drying time.

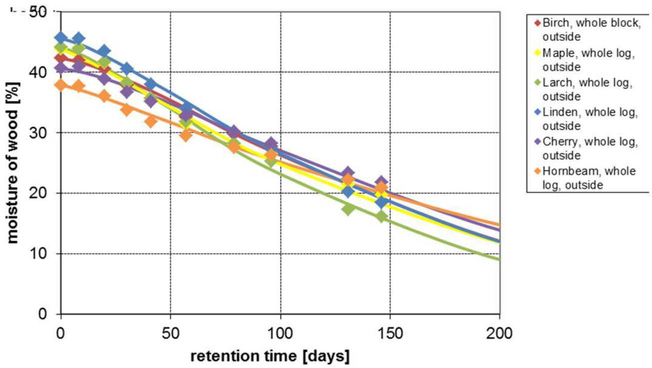

Fig. 13: The decrease in the moisture in the samples of whole wood logs stored outside.

Tab. 4: The constants of the Eq. 2.

	Whole wood logs-outside			Whole wood logs-inside			Quarter of logs-outside			Quarter of logs-inside		
	w_0 (%)	τ (-)	β (-)	w_0 (%)	τ (-)	β (-)	w_0 (%)	τ (-)	β (-)	w_0 (%)	τ (-)	β (-)
Birch	42.34	170	1.4	38.17	150	1.0	38.04	150	0.8	38.46	110	0.8
Maple	43.83	160	1.2	42.83	150	1.2	36.51	140	0.7	32.70	120	0.8
Larch	44.17	140	1.3	43.03	120	1.1	42.18	110	0.8	39.80	80	0.7
Linden	45.66	160	1.3	44.44	120	1.1	40.32	100	1.0	39.49	80	0.9
Cherry	40.65	190	1.4	39.05	210	1.0	41.36	150	0.9	38.08	140	0.8
Hornbeam	37.91	210	1.2	37.55	200	1.1	35.63	190	0.8	35.77	130	0.8
Poplar	-	-	-	-	-	-	48.65	100	1.0	46.39	90	1.0
Ash	-	-	-	-	-	-	30.24	230	0.7	28.38	150	0.9
Spruce	-	-	-	-	-	-	46.90	80	0.8	37.51	80	0.6
Oak	-	-	-	-	-	-	41.66	170	1.1	41.30	150	1.0

DISCUSSION

From the graphs of the drying rate, it is clear that at the beginning of the spring and summer periods, the drying is the fastest, and the rate gradually approaches zero. The highest drying rates were achieved by the representatives of light and medium-weight wood. The same results were achieved by the study of Fillbak et al. (2011). These results are probably due to higher water content of raw wood (freshly cut wood) leading to a higher drying force and faster water diffusion due to a greater porosity compared with that of the higher density wood species. The light wood in the form of whole and chopped logs, when cut before the start of the spring season, can reach the desired moisture by the end of the summer, regardless of whether they are stored indoors or outdoors under the shelter. The best harvesting for energy production was suggested to be in the spring and summer (Brand et al. 2011). Most of the drying was proposed to occur during summer and very little occurs during fall and winter (Nord-Larsen et al. 2011). Additionally, spring and early summer provides favourable conditions for drying forest fuels (Pettersson and Nordfjell 2007). For wood with a higher bulk density, the drying time is prolonged, and wood can be used as fuel in approximately 1 year. These results were confirmed by the study of Nord-Larsen (2011).

All types of tested wood, both in the form of whole and chopped logs, achieved the required moisture values in both storage environments after one year. The values of the moisture of wood stored outside under the shelter were approximately 4-7 wt% higher than those of the wood stored inside the building. If the wood was stored outdoors under a shelter during unfavourable microclimatic conditions (rainfall, snow), then there was a slight increase in the wood moisture. Recommendations by (Fillbak et al. 2011) suggest covering the already dried material with good air circulation. The shelter was found to be of great importance in maintaining the acceptable moisture of firewood during winter (Nord-Larsen et al. 2011). The year 2013 was a warm year in the Czech Republic, which accelerated the drying process. In the case of a less warm year and more rainfall, the balance is likely to worsen.

Under realistic conditions, the wood is stored more on top of each other and not very aerated. Additionally, the wood can also be stored in a shady, humid place, etc. Therefore, the following recommendations are suggested:

- The wood should be dried for at least one year. More than 3 years for wood drying is not beneficial in terms of the increased calorific value;
- Wood combustion increases the demand for space for the drying and storing of wood. In winter, dried wood should be moved into or by the boiler room to prevent a moisture increase due to unfavourable microclimatic conditions (rain, snow), and fresh wet wood should be dried outside under a shelter;
- Raw or very wet wood must be ventilated, otherwise biological decomposition (rotting) will start, resulting in a loss of the flammability and wood strength;
- Whole logs dry more slowly than the log quarters because the specific surface of the quarters is larger than of the whole logs. From the point of view of the drying rate of the wood, it is advisable to chop wood in wet matter. Raw wood is chopped more easily than dry wood and dries more quickly.

CONCLUSIONS

The representatives of light (poplar, spruce, linden), medium-weight (larch, maple, birch, ash, oak, cherry) and heavy (hornbeam) wood were dried in the period of one year. The whole logs and quarters of logs were stored inside a building and outside under a roof. The results of presented experiments of wood drying show that wood can dry in a well-ventilated roofed area in one year. In the case of whole logs, moisture content reached 16-21 wt% at the end of drying (zero drying rate) in the outdoor environment and 11-15 wt% in the indoor environment. In the case of the chopped logs (quarters of logs), the moisture content was stabilized up to 13-18% in the outdoor environment and 9-13% in the indoor environment. The attained moisture was lower than the recommended value of the wood moisture content for combustion (below 20 wt%). At the beginning of the spring and summer period, the drying is the fastest, and the rate gradually approaches zero. The highest drying rates were achieved by representatives of light and medium-weight wood.

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Horák Jiří, Kuboňová Lenka*, Tomšejová Šárka, Laciok Vendula, Krpec Kamil
Hopan František, Kubesa Petr, Kysučan Zdeněk, Ochodek Tadeáš
Všb-Technical University of Ostrava
Energy Research Center
17. Listopadu 15/2172
708 33 Ostrava – Poruba
Czech Republic
*Corresponding author: lenka.kubonova@vsb.cz
Phone: +420 597 324 905