

ACTA  
SILVATICA  
&  
LIGNARIA  
HUNGARICA

AN INTERNATIONAL JOURNAL  
IN FOREST, WOOD  
AND ENVIRONMENTAL  
SCIENCES

VOLUME 21, NR. 2  
2025

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## Species Seasonal Development of the *Ulmus* L. Genus in the Right-Bank Forest-Steppe of Ukraine and Features of Shoot Growth During the Vegetation Period



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### ABSTRACT

This study examined the features of the phenological phases in four *Ulmus* L. genus species by conducting phenological observations at the educational and production department of the Uman National University Bilohrudivskiy Forest, from 2022 to 2024, using accepted methods. The timing of the seasonal development phases in the *Ulmus* genus species corresponds with the phenological seasons, determined by natural and climatic parameters. A single-peaked curve with a peak from the first decade of May to the second decade of July characterizes indicators of shoot growth dynamics. Shoots of *Ulmus* L. grew to 77–83% of their total length by the end of July during the growing season before adding another 17–21% in August, indicating that, despite temperature variations, the studied species fully adapts to the research region conditions.

### TANULMÁNY INFÓ

#### Kulcsszavak:

Fenológiai megfigyelések  
Hőmérséklet-változások  
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### KIVONAT

**Az *Ulmus* L. faj szezonális fejlődése, nemzetség fejlődésének alakulása a jobb parti erdőssztyeppéken Ukrajnában, és a hajtásnövekedés jellemzői a vegetációs időszakban.** Az erdősztyeppében és a kertészetben széles körben használt négy *Ulmus* L. nemzetségg faj fenológiai fázisainak jellemzőit vizsgálták. A fenológiai megfigyeléseket 2022-2024 folyamán az Umani Nemzeti Kertészeti Egyetem Bilohrudivskij erdőben található oktatási és termelési részlegén végezték az általánosan elfogadott módszerek szerint, és megállapították, hogy az *Ulmus* nemzetség fajaiban a szezonális fejlődési fázisok időzítése megfelel a fenológiai évszakoknak, amelyeket a természeti és éghajlati paraméterek alapján határoznak meg. A hajtásnövekedés dinamikájának mutatóit egycsúcsú görbe jellemzi, amelynek csúcspontja a május első dekádjától július második dekádjáig tartó időszakban van, amikor a legintenzívebb növekedésük következik be. Július végén az *Ulmus* hajtáshossza eléri a vegetációs időszak alatti teljes hosszának 77-83%-át. Ez azt jelenti, hogy a vizsgált fajok a hőmérséklet-ingadozások ellenére teljes mértékben alkalmazkodtak a kutatási régió körülményeihez, és aktívan be lehet őket vezetni a kultúrába. Augusztusban a hajtások 17-21%-kal nőnek.

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## 1 INTRODUCTION

Research on plant growth and development patterns, coupled with the analysis of accumulated information during cultivation, is vital, both scientifically and practically. Plant seasonal development is particularly significant, especially in the context of the phylogeny process, as an adaptation to specific seasonal changes in climatic conditions (Batsaikhan et al., 2020). Lifecycle rhythms of a single species in different plantings and areas depend on botanical, geographical, phytocoenological, and environmental conditions (Antnova et al., 2019). The species phenorhythm of the genus occurs in such a way that the maximum development of plants occurs during a favorable period of the vegetation season. Endogenous and exogenous factors, including genetic characteristics and environmental conditions of the cultivation area, influence phenological development (Gordo–Sanz, 2010).

The dynamics of growth processes in woody plants change rapidly during seasonal changes (Solla et al., 2005; Uchendu et al., 2013; Välimäki et al., 2021). Consequently, their phenological development is defined as seasonal. Seasonal phenomena and their calendar dates of occurrence, which are inconstant, characterize each territory (Antonova et al., 2019, 2020, 2021).

A certain dependence between climatic factors (particularly changes in air temperature) and the annual plant development cycles has been revealed in recent decades. Scientists have noted several indicators whose seasonal development was sensitive to climate change (Chen, 1995; Menzel – Fabian, 1999). In addition, it was noted that the climate region has an impact on the timing of certain phenological phases (Schwartz, 1996). For example, Chen and Xu (2012) found that there is a greater phase dependence on temperature in milder areas than in harsher climates.

Similar studies of the seasonal development dynamics of certain plants in Europe and North America in temperate and Mediterranean climates have shown close to timely and successful development of all phases in plants without much delay (Bradley et al., 1999;; Menzel and Fabian, 1999; Beaubien and Freeland, 2000; Defila and Clot, 2001; Zhao and Schwartz, 2003; Gordo and Sanz, 2009; Myking and Skrøppa, 2007; Cruz et al., 2021). Such studies have not been conducted in the conditions of the Right-Bank Forest-Steppe of Ukraine.

The phenological phases of woody plants are indicators of climatic conditions. Observing them allows us to track tree responses to warming or precipitation changes and how species adapt to such conditions. Shifts in phenophases indicate climate change, which may help predict how global warming affects the growing season durations and ecosystem resources. *Ulmus* phenological growth patterns aid in the preparation of regional seasonal calendars for forestry. Such calendars are also used in the organization of environmental protection measures and pest and disease control of *Ulmus* species.

## 2 MATERIALS AND METHODS

Phenological observations of vegetative organ development of the *Ulmus* genus species (*U. laevis*, *U. glabra*, *U. pumila*, and *U. minor*) were conducted on the territory of the educational and production department of the Uman National University of Horticulture, Bilohrudivskyyi Forest, during 2022–2024 (*Figure 1*). Uniform temperature conditions characterize the entire territory of Ukraine. Therefore, we assume that the obtained results will be similar in all regions of the country.

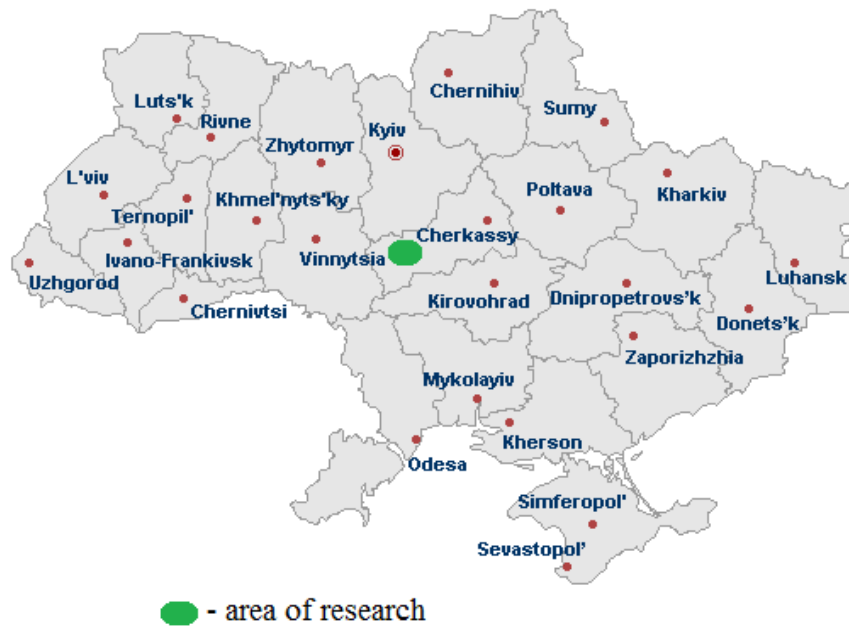


Figure 1. Map of Ukraine with the location of the research sites marked

All plants used for phenological observations grow in similar environmental conditions. The weather station is two to three kilometers from the research site.

We selected trees aged 20–30 years for our research. The height of the trees ranged from 10 to 15 m, and the trunk diameter ranged from 12 to 24 cm. The crown diameter ranged from 4 to 9 m.

Phenological observations of the generative and vegetative organs formation were conducted in 2022–2024 according to the method of Kalinichenko (2000) and Santini et al. (2004).

We conducted the research during the growing season and inspected the plots every two to four days for this purpose. Records were collected of the dates of the certain phenophase of each species under study. We selected ten trees of each species of the same age and size. The shoots from these trees were selected randomly from the middle of the crown.

Shoot growth characteristics during the growing season were found according to the Molchanov and Smirnov method (1967). Data was collected from the bud attachment point to the shoot of the previous year. Shoot lengths were measured with a metal ruler three days after the onset of the linear shoot growth phase. Data from the unfolded leaf attachment from the previous year's shoot was collected. The total number of shoots in each model group was 20 pcs. Daily gains were calculated after shoots stopped growing. Daily gains were defined as the difference in length between the next and the earlier values of each measurement period, divided by the number of days of this period. Measurements were performed following three days of intense growth and during the five days of decline afterwards. We recorded the average daily air temperature throughout this time. According to the study results, schedules of shoot growth during the vegetative season and of growth dynamics were drawn. The schedules recorded the dependence of shoot growth intensity on air temperature.

Observations followed model trees of different ages that had reached reproductive capacity. Phenological observations were conducted during the period of physiological activity. Observations were completed only once or twice a week in the summer when development is inhibited.

Based on the research results, we constructed graphs depicting shoot growth during the vegetation period. We established the growth dynamics and shoot growth intensity dependency on air temperature. Examining shoot growth duration and shoot growth dynamics

is vital to determining the winter hardiness of plants because shoots that finish growing early tend to be winter resistant, but slower-growing shoots can also achieve such resistance.

Statistical processing of the research results was performed with Excel. We calculated the Spearman rank correlation using Spearman's correlation coefficient, a nonparametric method that estimates the strength and direction of a monotonic (increasing or decreasing) relationship between two variables. Unlike Pearson's coefficient, Spearman's does not require normal data distribution. The calculation is based on the ranks of values in each variable, rather than on the numerical values themselves. We calculated Kendall's tau with the R program.

A temperate continental climate with warm and soft winters characterizes the research region. According to the Uman meteorological station, the average long-term air temperature is +7.2°C, with the coldest month (January) being minus 5.8°C and the hottest month (July) being 19.7°C. The average absolute minimum air temperature is -21°C. Extreme frosts are rare. The average daily temperature steadily exceeds +5°C in the first decade of April and +10°C in the third. The period with an average daily temperature above +10°C continues for 160–165 days. The duration of sunshine per year is 840 hours and 460–520 hours during the vegetation period. The average sum of daily temperatures above 0°C is 3155°C, +5°C - 3040°C, and +10°C - 2710°C. The weather is warm initially in the summer before turning hot in July and August.

The beginning of spring (steady transition of the average daily air temperature through 0°C) starts on March 15–20 (Table 1). However, late and early springs do occur.

Table 1. Average monthly temperature (°C) for 2022–2024 (according to the Uman weather station)

Year	Month												Year's average
	1	2	3	4	5	6	7	8	9	10	11	12	
2022	-4.7	0.5	4.5	9.6	17.0	23.4	20.0	20.7	15.6	10.0	5.5	2.2	10.4
2023	0.4	2.2	6.3	9.2	12.5	20.9	21.6	21.2	17.8	12.7	3.7	0.0	10.7
2024	-2.3	-3.8	2.0	7.4	14.0	19.8	23.2	20.3	13.0	7.2	4.7	1.3	8.9
Mean	-2.5	-0.4	4.3	8.7	14.5	21.3	21.6	20.7	15.4	9.9	4.6	1.2	9.9
Long-term mean	-5.7	-4.2	0.4	8.5	14.6	17.6	19.0	18.2	13.6	7.6	2.1	-2.4	7.4

Table 1 shows that the research years are characterized by slightly higher temperature values for individual months compared to the average long-term data. Frequent dry periods with air temperatures above 35 °C in the shade mark the spring and summer period. The annual mean air temperature over the years of investigation was +9.9 °C with a maximum of +29.9 °C (August 15, 2023).

### 3 RESULTS

The vegetation of the studied species begins when the maximum average monthly temperature reaches +17°C or above, the average daily temperature is in the range of +4.2 to 6.6°C, and the minimum is -2.0°C to 5.2°C.

The earliest bud swelling began in *U. laevis* in the third decade of March/first decade of April (March 23–April 4) and continued for 10–14 days. This phase started 4–6 days later in *U. glabra* (March 27–April 4) and continued for 10–12 days. The bud swelling phase was

simultaneously observed in the latest of the *Ulmus* species in our research, *U. pumila* and *U. minor* (March 29–April 4) and lasted 11–18 days (Table 2).

Table 2. The dates of shoot and leaf development in species of the genus *Ulmus* in Uman, 2022–2024

Species	year	Vegetative organs development date								
		Buds and shoots				Leaves				
		bud swelling	bud opening	start of shoots linear growth	end of shoot linear growth	leaf emergence starts	complete leaf emergence	leaf discoloration	falling leaves	leaf fall end
<i>U. pumila</i>	2022	12.04	24.04	03.05	26.08	28.04	01.08	02.10	16.10	19.10
	2023	15.04	23.04	01.05	01.09	26.04	09.08	36.09	13.10	16.10
	2024	30.03	20.04	29.04	23.08	26.04	03.08	28.10	01.11	14.11
<i>U. glabra</i>	2022	31.03	18.04	26.04	23.08	25.04	30.07	25.09	05.10	12.10
	2023	07.04	21.04	30.04	30.08	01.05	05.08	18.10	22.10	30.10
	2024	27.03	15.04	24.04	25.08	22.04	28.08	18.10	23.10	30.10
<i>U. laevis</i>	2022	03.04	12.04	21.04	21.08	23.04	30.07	28.09	02.10	11.10
	2023	10.04	19.04	28.04	27.08	23.04	03.08	12.10	20.10	29.10
	2024	23.03	11.04	20.04	17.08	19.04	28.07	15.10	26.10	02.11
<i>U. minor</i>	2022	08.04	21.04	01.05	25.08	25.04	27.07	03.10	17.10	19.10
	2023	13.04	23.04	04.05	03.09	29.04	03.08	17.10	28.10	13.11
	2024	29.03	17.04	25.04	20.08	21.04	25.07	26.10	28.10	05.11

Budding began in the second to third decade of April during the research years on species and forms of the genus *Ulmus*. The earliest budding was seen in *U. laevis* (April 11–April 19), which lasted 7–9 days. The latest among the studied species was in *U. pumila* (April 20–April 24) and *U. minor* (April 17–April 24).

The linear shoot growth started the earliest in *U. laevis* (20.04–28.04) and *U. glabra* (March 24–April 30). The phase of linear growth occurs 4–9 days later in *U. pumila* and 6–10 days in *U. minor* than in *U. laevis*. Shoot growth completion was noted when the last leaves were finished expanding.

The change in leaf color was most clearly seen in *U. laevis* (September 28–October 23). Under favorable conditions, the color change occurred in the third decade of September and the second decade of October in other *Ulmus* species. The consistently warm autumn of 2023 delayed the discoloration and leaf fall phase, which occurred 15–20 days later than in 2021 and 2022. The life processes in plants are inhibited after leaf fall, and they enter a dormant state.

Research on seasonal shoot growth of species and forms of the genus *Ulmus* indicates that the conditions of the Right-Bank Forest-Steppe of Ukraine induce a growth period of 86 to 127 days. Growth process lengths depend on the biological characteristics of the species.

The linear growth of shoots in all representatives of the genus *Ulmus* began at the same time, at the beginning of the third decade of April.

During all the research years, the shoot growth of *U. laevis* was observed from the transition of the budding phase at the end of the second and beginning of the third decade of April on average (Figure 2).

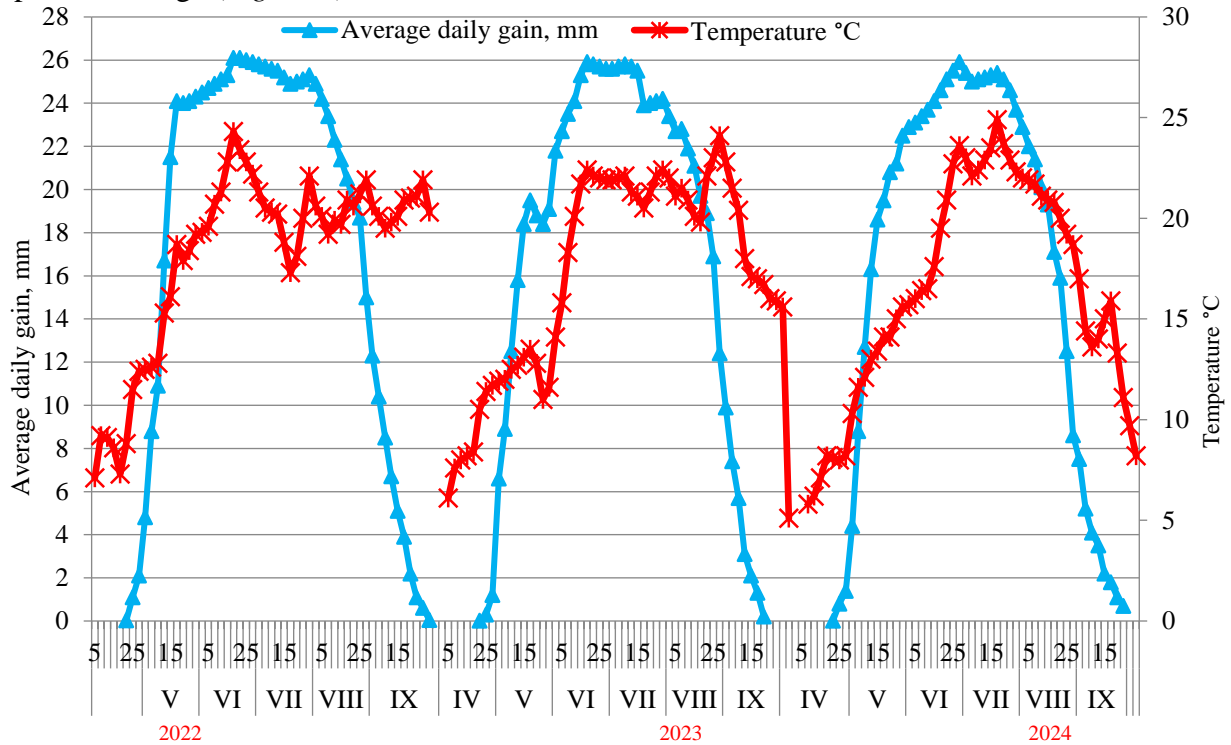


Figure 2. Seasonal growth dynamics of *U. laevis* during 2022–2024

The budding phase transition occurred when the average daily temperature exceeded  $+11.5^{\circ}\text{C}$  in 2022 and 2023. Shoot growth was observable at temperatures above  $+8^{\circ}\text{C}$  during the slightly colder spring of 2024. Furthermore, daily shoot growth intensified as the temperature increased. The culmination of the species shoot growth for all years varied by dates but occurred in mid-June and was 25.9–26.1 mm per day. For example, there was a rapid increase in temperature to  $+23$ – $24^{\circ}\text{C}$  in the second decade of June 2022, which caused an average daily growth of 26 mm per day. Then, the growth intensity gradually decreased as the temperature dropped. July 2024 recorded a significant increase in temperatures above  $+24^{\circ}\text{C}$ , which was higher than in June.

According to the research, *U. glabra* begins vegetation at the same time as *U. laevis* on a 3-year average and is dependent on air temperature to some degree (Figure 3).

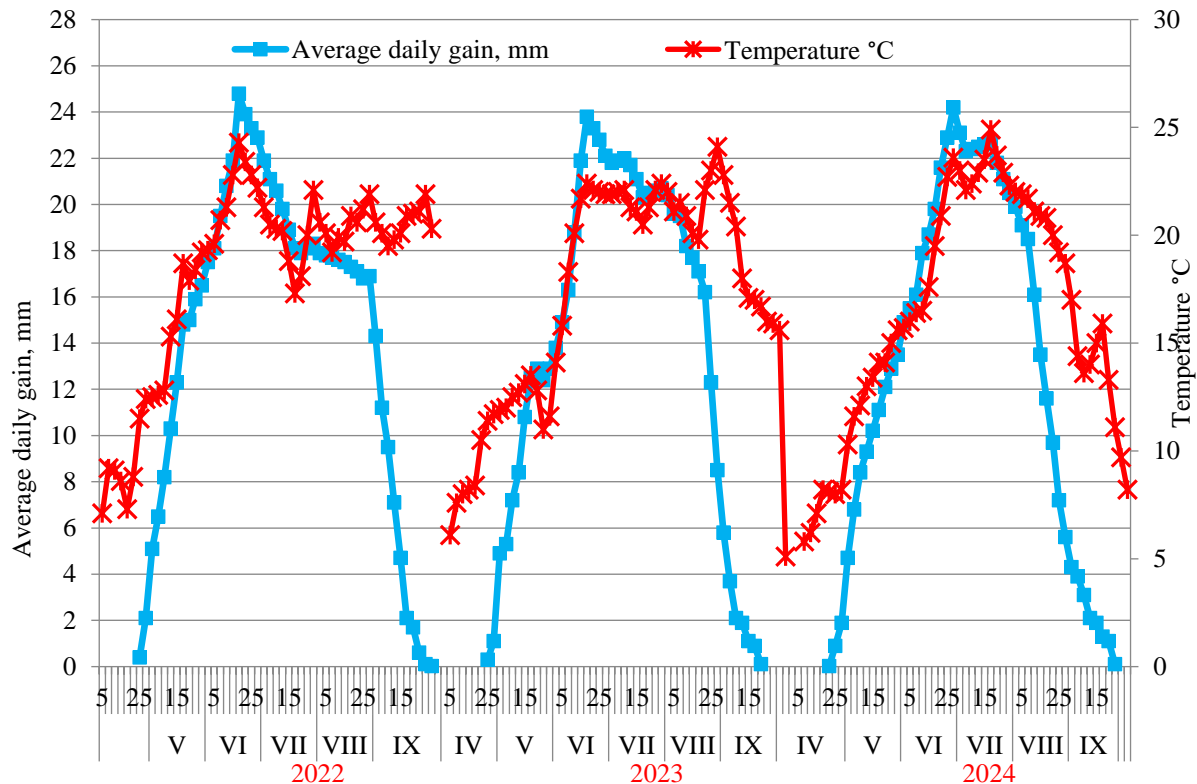


Figure 3. Seasonal growth dynamics of *U. glabra* in 2022–2024

Compared to the species above, *U. glabra* has slightly lower average daily growth value and intensity values. However, it has a rather clear dependence on temperature variations at the beginning of shoot growth and before culmination, so the maximum growth value matches the maximum temperatures of this period. The growth value for *U. glabra* is 23.1–24.2 mm per day, except for 2024 when the highest air temperature for the season was recorded in the second or third decade of August, and growth intensity had already begun to decline. However, there was a slight jump in growth. For this reason, the correlation coefficient here was 0.79, the highest for all years. There were frequent, rapid increases and decreases in temperature by several degrees starting in the third decade of August 2022; however, this had no significant impact on shoot growth during the growing season. The correlation coefficient, which in this case was 0.73, confirmed this. As for 2023, the highest temperature for the season (+24.1°C) was observed at the end of the third decade of August, when the shoots were nearly grown and preparing for dormancy. Therefore, it did not affect growth.

*U. pumila* starts vegetation 4–6 days later than the previously-mentioned species and has a lower shoot growth rate (Figure 4).

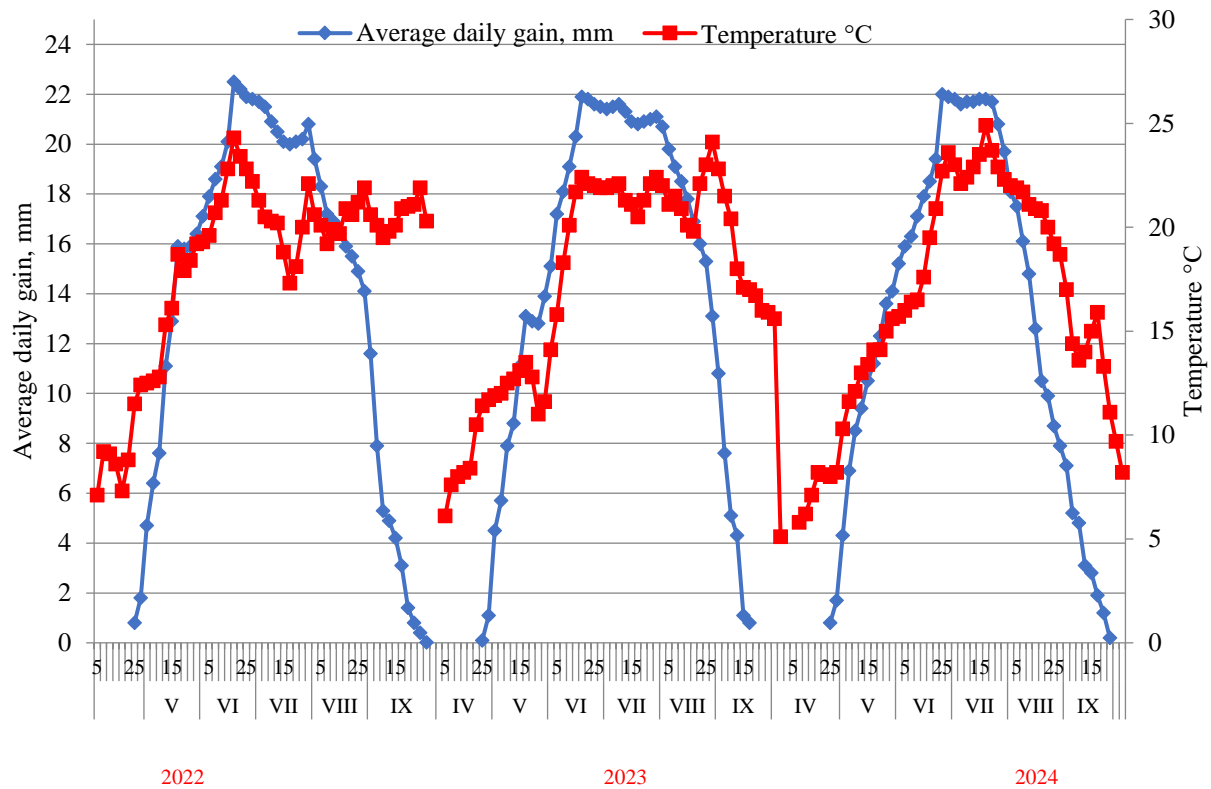


Figure 4. Dynamics of seasonal growth of *U. pumila* during 2022–2024

*U. glabra* had a shoot growth length of 24.2 mm at the culmination. For *U. laevis*, this figure was 26.1 mm, while for *U. pumila* it was 22.2 mm.

Thus, *U. pumila* showed a greater dependence of growth intensity on temperature changes. The graphs clearly show that after the shoot growth culminated in June, a second wave of growth was seen when the temperature increased in a specific period. In 2022, this was observed in the second decade of July, when a rapid rise in temperature above 21°C caused a short-term jump in growth to 21 mm per day. In 2023, from the first decade of June to mid-July, the air temperature was the same (except for the last days of the first decade of July). This contributed to the fact that the shoot growth curve was also stable during this period. However, the elevated temperatures of September did not affect growth. In 2024, the highest temperature was recorded in the third decade of June (+23.6°C) and in the second decade of July (+24.9°C). In both cases, there was a jump in growth intensity, up to 21.9 mm and 21.8 mm, respectively.

*U. minor* shoots start growing slightly later than *U. pumila* shoots. In general, these two species begin growing simultaneously with a difference of several days (Figure 5).

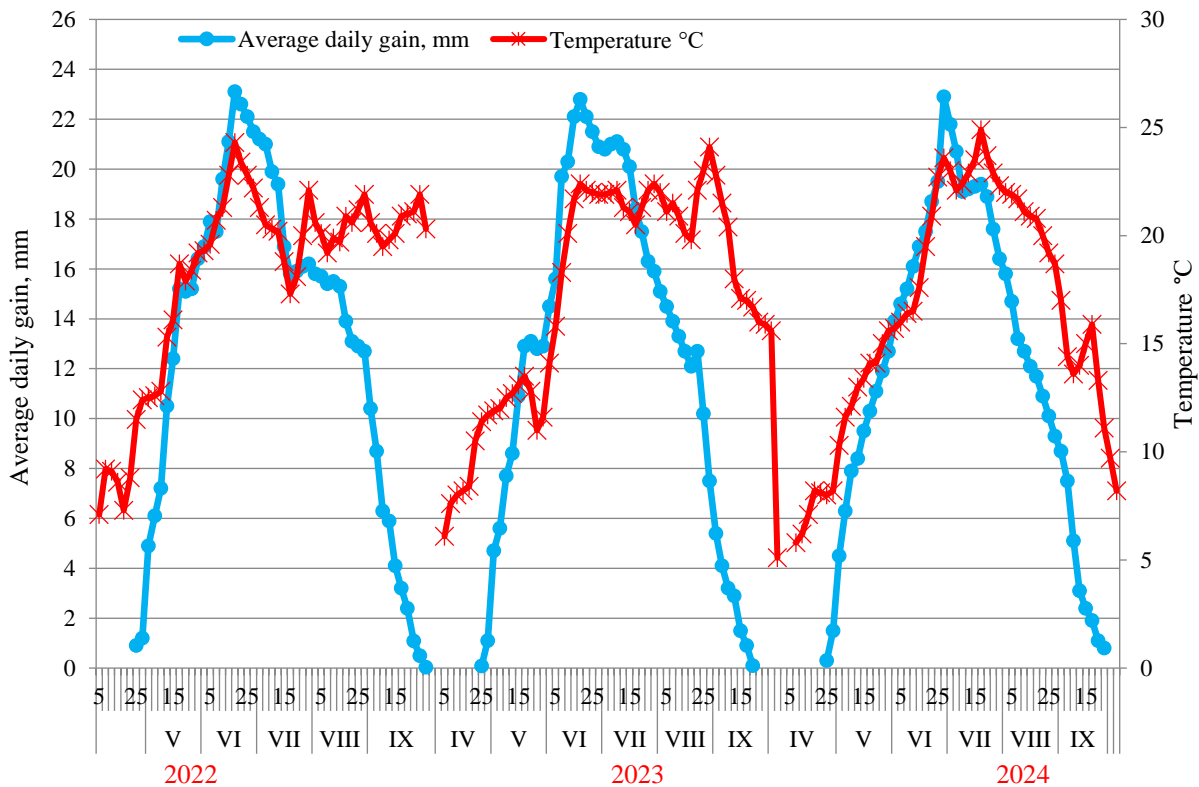


Figure 5. Seasonal growth dynamics of *U. minor* in 2022–2024

*U. minor* shoots showed a weak reaction to temperature changes at the beginning of their growth. Their average daily growth ranged between 4 and 7 mm and began to increase more intensively at a temperature of +13–15°C. Shoot growth was uniformly steady despite some temperature changes. A rapid increase in the average daily growth and the subsequent culmination of the temperature occurred in the first and second decades of June and matched the maximum air temperature during this period. At that time, the growth rate of this species was 22.5 mm per day. After that, growth intensity declined with different dynamics over the years. For example, starting in the second decade of June 2022, the temperature dropped by several degrees, and the drop in growth was quite clearly accompanied by the same dynamics. From the second decade of August, temperature changes of 1–2°C began to occur; however, growth intensity was steadily declining. The temperature in the second to third decade of June 2023 did not show such rapid changes, and we can see a smooth increase in growth. This contrasts with 2024, where the increase in air temperature after the culmination had almost no effect on shoot growth.

During the statistical processing of the data, we determined the coefficient of determination, which measures the dependence of dependent variables (different species growth) on the variation of independent variables (temperature) (Table 3).

The statistical data reveal a moderate positive relationship: as the temperature rises, the tendency for shoot growth increases. The probability of such a relationship occurring by chance is extremely low, indicating that the result is statistically significant. The data presented denotes a stable monotonic relationship between temperature and growth. The strength of the correlation increases slightly from 2022 to 2024 for all species, showing a strengthening of the linear dependence. Kendall's  $\tau$  coefficient has marginally lower values but confirms a stable rank (monotonic) dependence.

Table 3. General statistical analysis of the dependence of shoot growth on temperature during the growing season, 2022-2024.

Year	Species	Statistical analyses			
		Kendall's $\tau$	p-value ( $\tau$ )	Spearman's $\rho$	p-value ( $\rho$ )
2022	<i>U. pumila</i>	0.437	<0.001	0.557	<0.001
	<i>U. glabra</i>	0.483	<0.001	0.611	<0.001
	<i>U. laevis</i>	0.415	<0.001	0.543	<0.001
	<i>U. minor</i>	0.447	<0.001	0.567	<0.001
2023	<i>U. pumila</i>	0.426	<0.001	0.548	<0.001
	<i>U. glabra</i>	0.472	<0.001	0.609	<0.001
	<i>U. laevis</i>	0.421	<0.001	0.556	<0.001
	<i>U. minor</i>	0.458	<0.001	0.571	<0.001
2024	<i>U. pumila</i>	0.468	<0.001	0.648	<0.001
	<i>U. glabra</i>	0.501	<0.001	0.701	<0.001
	<i>U. laevis</i>	0.436	<0.001	0.589	<0.001
	<i>U. minor</i>	0.474	<0.001	0.617	<0.001

If we characterize the dependencies of shoot growth for each species separately, we can see that *Ulmus pumila* is characterized by a stable, moderately strong positive correlation in all the study years. However, in 2024, the correlation significantly increased (especially  $r = 0.883$ ), showing a strong linear dependence of shoot growth on temperature. The same applies to *Ulmus glabra*.

Unlike the species described above, *Ulmus laevis* had a moderate dependence in 2022–2023, which intensified in 2024 ( $r = 0.827$ ). In contrast, *Ulmus minor* had a consistently strong positive correlation throughout all years.

#### 4. DISCUSSION

The timing of the onset of the seasonal development phases in *Ulmus* species corresponds to the phenological seasons, which are distinguished on the basis of natural and climatic parameters (Puzrina – Yavny, 2020). Seasonal rhythms comparison of the *Ulmus* species development showed that they are not significantly different. In general, the onset of phenological phases in the studied species was parallel. The research results on phenological rhythms of development in *Ulmus* species in another region of Ukraine nearly coincide with ours (Stupak, 2024). The shoot growth phase is particularly significant. After all, how long shoots grow depends on the lignification level and, thus, on frost resistance and winter hardiness.

The unexplained variance was the influence of other climatic factors. However, a significant percentage remained for other influencing factors, which is a reason to consider such influences in further research. Weather conditions have a notable impact on the onset of phenological phases. Earlier studies on the dependence of budding and the sum of some temperatures have been conducted (Cannell – Smith, 1983; Murray et al., 1989; Hunter – Lechowicz, 1992; Välimäki et al., 2022).

Some research suggests that temperatures of the previous growth season cause changes in the onset of phenological phases (Chmielewski – Rötzer, 2001; Menzel, 2003; Gordo – Sanz, 2010) and applies to both the early spring and late autumn vegetation (Menzel, 2003; Matsumoto et al., 2003; Gordo – Sanz, 2010). However, other factors such as daylight

hours, precipitation, humidity, and even wind strength are thought to influence the end of the growing season in autumn (Chen – Xu, 2012; Hwa et al., 2021). In addition, plants must undergo a dormant state; otherwise, they will not start growing even under favorable temperature conditions (Wareing, 1956; Nitsch, 1957; Vegis, 1964; Välimäki et al., 2022).

The favorable weather conditions in 2022 induced the onset of phenological phases 3–9 days earlier than in 2023 and 2024. Indicators of seasonal dynamics reflect the adaptive features of the studied species to the growing conditions.

The onset of the phenological phases varies significantly by year. For example, the beginning of leaf budding to complete swelling takes 9 to 18 days. Significant temperature changes help explain this trend, under which shoot development accelerated and slowed down. The growth rate of annual vegetative shoots varied over the entire period. The most significant growth in the species studied occurred up to the second decade of July. After that, the growth processes slowed down significantly. The annual shoot growth indicators are related to the sample ages on which the measurements were made. This parameter is 6.5–7 higher in three-year-old plants than it is in 70-year-old plants. Twelve-year-old plants displayed parameters that were 4.5–5 times higher than in 70-year-old plants.

The difference in shoot growth intensity in adult and young plants is explained by the fact that young seedlings use nutrients only for shoot growth and development, while older ones form generative organs. Early termination of shoot growth in adult plants contributes to better wood maturation and, compared to young individuals, to better adaptation to autumn and winter temperature drops. The largest increase over the research years was seen from the third decade of April to the second decade of July. Thus, *Ulmus* shoots reached 77–83% of their total growth during the growing season by the end of July. *Ulmus* species have only one main growth wave, after the culmination of which the growth rate decreases significantly, despite temperature changes. Starting from the second decade of August, growth begins to decline intensively. At this time, the shoots grew by 17% and 21%. In September, shoot growth decreased to 3% of the total growth during the growing season. In the second decade of September, an increase in temperature above +15°C did not affect growth intensity, because the shoots were already preparing for wintering.

The maximum shoot growth intensity in adults of the studied species and forms of the genus *Ulmus* was recorded in the first half of the growing season. In our opinion, such dynamics of annual vegetative shoots growth and their duration explain the high winter resistance of *Ulmus* species because an early completion of growth processes (early budding, more complete lignification of annual shoots, and wood ripening) causes the appropriate time for the decline of growth processes at the cellular level. This characteristic of growth processes contributed to the timely shoot lignification of *Ulmus* species and forms.

## 5 CONCLUSIONS

The vegetation of the researched species begins in the third decade of April. The earliest bud swelling began in *U. laevis* in the third decade of March/first decade of April (March 23–April 10) and continued for 10–14 days. This phase started 4–6 days later in *U. glabra* (March 27–April 7) and was 10–12 days. In the *Ulmus* species that proved to be the latest, the bud swelling phase occurred simultaneously in *U. pumila* and *U. minor* (March 29–April 4) and continued for 11–18 days. The duration of a particular phenological phase in elms is closely related to weather conditions. Calculating the determination coefficients showed that temperature and other climatic factors influence plant growth and development. Indicators of shoot growth dynamics are characterized by a single-peaked curve with a peak in the period from the first decade of May to the second decade of July, when the most intensive growth

occurs. *Ulmus* shoot lengths reach 77–83% of their total length during the growing season at the end of July. The shoots grow by 17%–21% in August, indicating that the studied species are fully adapted to the conditions of the research region and can be actively introduced into culture despite temperature variations.

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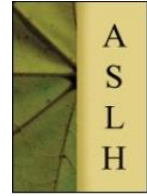
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# Comparative Air Flow Analysis Between Johor and Szombathely: Evaluating Woodcarving Ventilation Panels



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## ABSTRACT

This study explores the potential of using woodcarving ventilation panels to enhance natural ventilation (NV) in buildings, particularly in extreme climate conditions in two different locations: Johor, Malaysia, and Szombathely, Hungary. The main aim is to assess how these panels contribute to airflow dynamics and temperature regulation within buildings. The research employs Computational Fluid Dynamics (CFD) simulations to model airflow and temperature distribution in identical building models subjected to high wind speeds and temperatures, simulating worst-case scenarios. The findings reveal that while Johor experiences moderate wind speeds resulting in steady but less dynamic airflow, Szombathely benefits from stronger winds, producing more effective ventilation and cooling. These results suggest that woodcarving panels can improve airflow and thermal comfort but are more effective in areas with higher wind speeds. The study concludes that while NV is beneficial, integrating HVAC systems is essential for maintaining optimal comfort in extreme conditions.

## TANULMÁNY INFÓ

### Kulcsszavak:

Fafaragásos táblák  
Természetes szellőzés  
CFD szimulációk  
Légáram dinamikája  
Hőkomfort

## KIVONAT

**Johor és Szombathely szélviszonyainak összehasonlító elemzése: fafaragásos szellőzőablak táblák értékelése.** Jelen tanulmány a fafaragásos szellőzőablak táblák természetes szellőzés fokozásában betöltött szerepét vizsgálja szélsőséges klimatikus körülmények mellett két különböző helyszínen: Johor, Malajzia és Szombathely, Magyarország. Azt vizsgáljuk, hogy mennyire járulhatnak hozzá az ilyen táblák a légáramok dinamikájához és a hőmérséklet szabályozásához az épületen belül. A kutatás során a Numerikus Folyadék Dinamika módszerét használtuk a légáram és hőmérsékleteloszlás modellezésére a legrosszabb esetben megfelelő magas környező hőmérsékleti és szélsébségi viszonyok azonos kialakítású épületekre való alkalmazásával. Megállapítottuk, hogy míg Johor esetében a jellemző mérsékelt szélsébség stabil, de kevésbé dinamikus légáramokat eredményez, Szombathely előnyt élvez a hatékonyabb szellőzést és hűtő hatást eredményező erősebb széljárásból. Az elemzés eredményei arra utalnak, hogy a fafaragásos táblák javíthatják a belső légáramokat és a hőkomfortot, de hatékonyságuk a magasabb szélsébségű helyszíneken érvényesül. A tanulmány fő következtetése, hogy míg a szellőzőablak táblák nyújtotta természetes szellőzés értékelendő, szükséges lehet fűtő-szellőző és légkondicionáló (HVAC) rendszerrel való integrálása az optimális komfortérzet fenntartására extrém körülmények között is.

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## 1 INTRODUCTION

Natural ventilation (NV) has long been a fundamental strategy in vernacular architecture, particularly in tropical and temperate climates, to enhance indoor thermal comfort and reduce reliance on mechanical cooling systems (Abdul Rahim and Szabó, 2023). Across cultures, traditional ventilation methods, such as woodcarving ventilation panels, have been employed to facilitate airflow while preserving aesthetic and cultural identity (Abdul Rahim – Kovács, 2024; Muhammad – Rosdi, 2023; Yusof et al., 2020). Traditional designs often incorporate NV strategies, such as cross ventilation and wind catchers, which enhance thermal comfort and air quality (Michael et al., 2014; Pan et al., 2024). In Malaysia, the intricate woodcarving panels of traditional Malay houses intensify passive cooling. These panels allow air to flow freely while maintaining privacy and aesthetic value, playing a crucial role in optimising indoor thermal conditions (Tong et al., 2024). While woodcarving elements are prominent in Malaysian architecture, similar decorative wooden structures exist in Hungarian heritage architecture, such as the Székely gate, which is primarily constructed from wood, showcasing traditional craftsmanship that emphasises organic architecture principles (Jeffrey, 1995). However, these Hungarian structures primarily serve symbolic and ornamental purposes rather than ventilation. The design of these gates reflects traditional craftsmanship, serving as ornamental features that enhance the aesthetic appeal of rural architecture (Preda et al., 2018). Inspired by the functional use of woodcarving panels in Malay architecture, this research explores their potential integration into Hungarian housing to improve NV in temperate climates.

Previous studies highlighted the role of woodcarving ventilation panels in optimising NV in tropical climates. Traditional Malay houses utilise NV to achieve thermal comfort, with optimal indoor temperatures ranging from 25°C to 27°C (Alkausar – Riyani, 2023; Nik Hassin – Misni, 2023). In contrast, Hungarian vernacular architecture has been studied mainly for its thermal insulation properties rather than NV. The use of heavy materials, such as brick or stone, helps to absorb heat during the day and release it at night, maintaining a stable indoor temperature (Sood, 2023). Comparative studies of NV across different climatic regions have been conducted, concluding that regional climate conditions significantly influence the efficiency of passive ventilation strategies. In arid and semi-arid regions, cross-ventilation with opposing windows significantly improves NV rates, achieving substantial energy savings. Windcatchers further enhance ventilation and reduce cooling demand (Ayoobi et al., 2024). They are effective in improving air quality and reducing energy consumption for air conditioning in tropical climates, even with slight temperature differences between indoor and outdoor spaces (Bernal et al., 2024). Additionally, with climate change causing higher summer temperatures in Hungary, the need for improved passive ventilation solutions has become increasingly important (Fürtön et al., 2022). However, no direct comparison has been made between NV performance in Malaysia and Hungary using the woodcarving ventilation system.

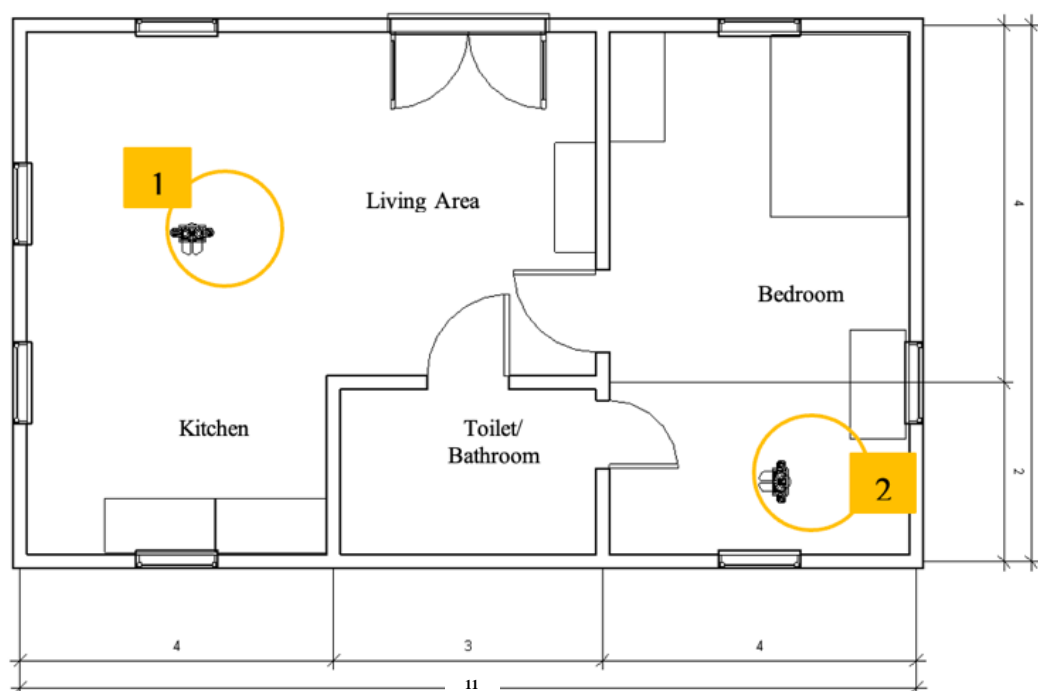
This study presents a comparative simulation of NV performance through traditional woodcarving ventilation panels in two distinct climatic zones, tropical Johor Bahru, Malaysia, and temperate Szombathely, Hungary. By integrating cultural woodcarving designs into ventilation strategies and analysing airflow performance through transient CFD simulations, this research bridges architectural heritage with environmental performance. The novelty lies in applying traditional woodcarving ventilation in both local and foreign contexts and evaluating its effects under real summer weather conditions. This cross-cultural and cross-climatic analysis offers new insights into how culturally significant designs can be adapted for contemporary passive ventilation strategies across diverse regions.

## 2 MATERIALS AND METHODS

This study employed CFD simulations to analyse the effectiveness of woodcarving ventilation panels in enhancing NV in two distinct climates: Johor, Malaysia (hot-humid climate) and Szombathely, Hungary (temperate climate). The methodology consists of computational modelling and simulation analysis. To evaluate thermal comfort in the studied buildings, we used the ASHRAE 55 standard (2020) as the primary guideline for determining acceptable comfort conditions. According to this standard, thermal comfort is influenced by factors such as temperature, humidity, and air velocity (Agrawal and Tiwari, 2010; Olesen and Brager, 2004). To assess the adequacy of passive airflow, we measured indoor temperatures, relative humidity, and air velocity across the room.

### 2.1 Computational Modelling

The floor plan in *Figure 1* features an 11m x 6m floor plan with a 3.5m ceiling height designed to optimise NV. Two human figures are positioned to simulate thermal comfort—one between the living and kitchen areas and another in the bedroom. The floor plan includes multiple rooms, seven windows, and ten woodcarving ventilation panels, such as those above the main entrance and bathroom shown in *Figure 2*. These panels integrate traditional motifs, enhancing airflow and preserving cultural significance. The open interior doors mimic typical usage, further promoting air circulation. This setup enables the analysis of how woodcarving elements affect airflow and thermal comfort in modern architecture.



*Figure 1. Floor plan*

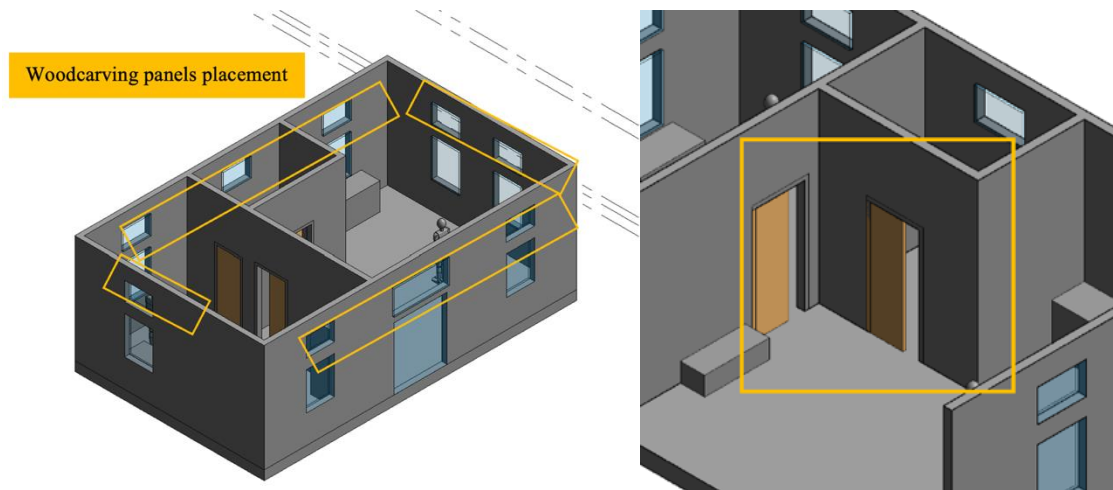


Figure 2. Woodcarving placements and interior doors' position

The woodcarving designs from Rumah Limas Hutan Bandar MBBB and Székely Gate motifs were implemented as ventilation panels in the CFD models for the Johor and Szombathely simulations. These 3D models demonstrate how traditional woodcarvings, such as the *ukiran kerawang tebuk tembus* and *Ketumbit* flower motifs from Rumah Limas and the *kaputükör* design from Székely gates, can be integrated into modern architecture. The carvings, categorised by their void-to-total area ratios, were scaled to fit the building openings in Autodesk Revit to ensure consistency in panel sizes for the simulations.

Table 1. Woodcarving ventilation panels placement.

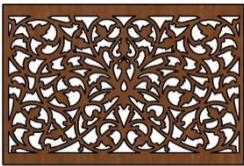



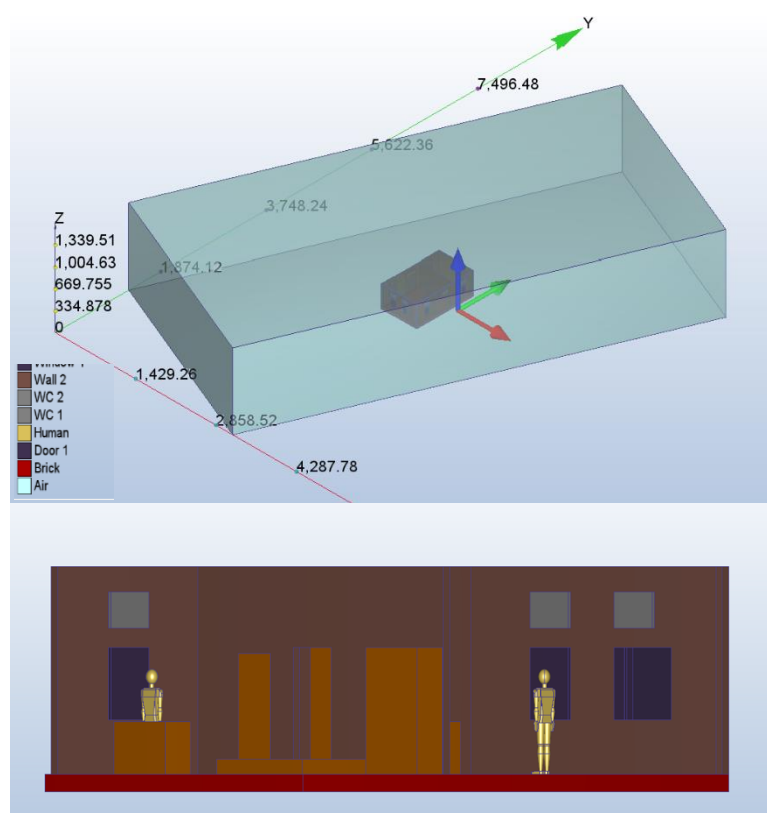
Location	Code	Panel	Description
Above the windows & toilet wall	WC1		<ul style="list-style-type: none"> <li>• QTY: 8 Nos</li> <li>• 609.6 mm x 914.4 mm</li> </ul>
Above the main entrance	WC2		<ul style="list-style-type: none"> <li>• QTY: 1Nos</li> <li>• 800 mm x 1800 mm</li> </ul>
Above the windows & toilet wall	WC3		<ul style="list-style-type: none"> <li>• QTY: 8 Nos</li> <li>• Size: 609.6 mm x 914.4 mm</li> </ul>
Above the main entrance	WC4		<ul style="list-style-type: none"> <li>• QTY: 1 Nos</li> <li>• Size: 800 mm x 1800 mm</li> </ul>

Table 1 shows the woodcarving panels (WC1, WC2) placed above windows and the bathroom wall, with one larger panel above the main entrance in the Johor situation. In

Szombathely, similar arrangements were made, with panels (WC3 and WC4) located above windows, the bathroom wall, and the main entrance. These panels, varying in size from 609.6 mm x 914.4 mm to 800 mm x 1800 mm, were chosen for their ability to enhance ventilation while preserving cultural motifs. This integration facilitates NV while contributing to the aesthetic and cultural significance of the designs.

## 2.2 Simulation Setup

Following Autodesk tutorial guidelines, an external air volume extending beyond the building geometry - three times the building height and five to six times the width and depth - was defined for the CFD simulations to ensure accurate airflow modelling without boundary interference. This volume, with dimensions of 12891 cm in height, 34126 cm in width, and 67000 cm in depth, was positioned at an angle of  $-22.5^\circ$  to simulate real-world wind conditions, as shown in *Figure 3*. Materials were also assigned to the building geometry.



*Figure 3. Geometry setup on CFD Autodesk*

CFD simulations were conducted under steady-state conditions using the following boundary conditions to replicate real-world climate conditions in Johor, Malaysia, and Szombathely, Hungary. The materials used for the buildings in each location were updated to ensure accurate thermal performance and airflow simulations, considering the specific climate conditions of both regions.

The wind speeds of 7 m/s (for Johor) and 14 m/s (for Szombathely), as shown in *Table 2*, represent the highest recorded values during the selected days, 28–29 July 2022, for both Johor and Szombathely. These values were chosen to simulate peak environmental stress during extreme conditions. For Johor, the data were obtained during a site visit at Rumah Limas Hutan Bandar MJB. For Szombathely, the weather data were extracted from the Energy Plus Weather (EPW) file corresponding to the same dates. While such high wind speeds are not typical of average summer conditions (e.g., Szombathely's summer average is  $\sim 2.5$  m/s), they

were intentionally used to assess the robustness of NV under boundary conditions that may occur during rare but impactful climatic events.

*Table 2. Boundary conditions for Johor and Szombathely*

Boundary condition	Value (Johor)	Value (Szombathely)	Surface/Volume
Temperature	32°C	34°C	South (Johor) & North-Northwest facing (Szombathely) external air volume
Velocity	7 m/s	14m/s	South (Johor) & North-Northwest facing (Szombathely) external air volume to simulate wind flow
Pressure	0 Pa	0 Pa	North (Johor) & South-Southeast facing (Szombathely) external air volume, acting as the outlet.
Film coefficient	20 W/m <sup>2</sup> K	20 W/m <sup>2</sup> K	Entire outer surface of the building
Human	60 W/m <sup>2</sup> K	60 W/m <sup>2</sup> K	Two human figures positioned within the building to assess thermal comfort

The building materials for both regions were modified as detailed in *Table 3*. These materials represent typical components found in Malaysian and Hungarian buildings, ensuring realistic thermal simulations.

*Table 3. Materials for both buildings*

Material	Johor Building	Szombathely Building
Walls	Material: hardwood, thermal conductivity: 0.16 W/mK	Material: Brickwork thermal insulation, eq. thermal conductivity: 0.065 W/mK
Windows	Default CFD	Material: Window (solar), Thermal conductivity: 0.2 W/mK
Entrance door	Default CFD	Material: Window (solar), Thermal conductivity: 0.23 W/mK

*Woodcarving Panel Representation:* The woodcarving panels used in the simulation presented a challenge due to their complex geometry, which could not be directly imported into Autodesk CFD. To address this, a Free Area Ratio (FAR) was calculated for each panel to represent airflow resistance. The FAR was used to define the panels as resistive boundaries, enabling an accurate representation of their influence on airflow.

The FAR was calculated using the formula:  $FAR = \frac{Open\ Area}{Total\ Area} \times 100$

This ratio is crucial for assessing a panel's potential to enhance NV. Panels with a higher FAR, such as WC3 and WC4, are more effective in promoting airflow, while WC1 and WC2 provide a balance between structural integrity and ventilation. While FAR is a widely used

static indicator to estimate the potential for NV, its applicability under high wind speeds must be interpreted with caution. At elevated wind velocities, airflow behaviour is influenced not only by the size of the openings but also by pressure distributions, turbulence, and vortex formation. Therefore, FAR in this study serves as an initial comparative metric of panel openness rather than a definitive predictor of ventilation efficiency. The CFD simulations provide a dynamic understanding that complements FAR by capturing real airflow phenomena such as jetting, separation, and recirculation that FAR alone cannot represent (*Table 4*).

*Table 4. Free area ratio*

Woodcarving Panel	FAR
WC1	0.4314 or 43.14%
WC2	0.3773 or 37.73%
WC3	0.4657 or 46.57%
WC4	0.4485 or 44.85%

### 3 RESULTS

This section presents a detailed analysis of the CFD simulation results for airflow and temperature distribution in two different climates: Johor, Malaysia (hot-humid climate) and Szombathely, Hungary (temperate climate). The simulations focus on the effectiveness of woodcarving ventilation panels under extreme conditions. Identical building models were used for both regions to ensure a consistent basis for comparison.

#### 3.1 Airflow Distribution and Velocity Magnitude

*Figure 4* illustrates the air circulation pattern in the Johor case study. The airflow pattern in the figure shows a combination of smooth directional flow and localised circulation. Air enters the building through openings, creating a generally consistent horizontal flow across most rooms. In certain areas, especially near corners and around partitions, the vectors curve and form swirling patterns, indicating vortex formation and recirculating zones. These vortices suggest reduced airflow efficiency in those regions. The direction and density of the streamlines also show how air is guided by the room layout, with some zones experiencing faster, more concentrated flow, particularly along narrow paths between openings. *Figure 5* illustrates the airflow distribution inside the building, with wind velocities ranging from 0 to 3.5 m/s in (a) and 0 to 2 m/s in (b) Johor. These velocities fall within the range considered beneficial for NV according to ASHRAE 55, which notes that air speeds up to around 0.8 m/s are generally comfortable for occupants under warm conditions, and higher speeds may enhance thermal comfort through convective cooling. However, excessively high speeds may lead to discomfort due to drafts. The variation in velocity indicates the dynamic nature of airflow through different parts of the building, with higher velocities potentially improving heat dissipation and indoor air quality, especially in open-plan spaces or near openings. In the figures, the visibility of red colour was used to indicate areas with the highest wind speeds or velocities, providing a clear visual reference for airflow intensity across the interior space.

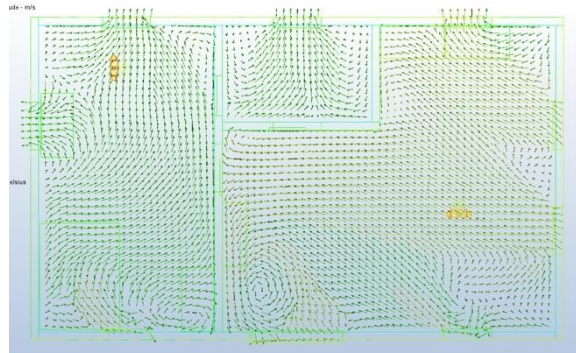


Figure 4. Overall air circulation in Johor

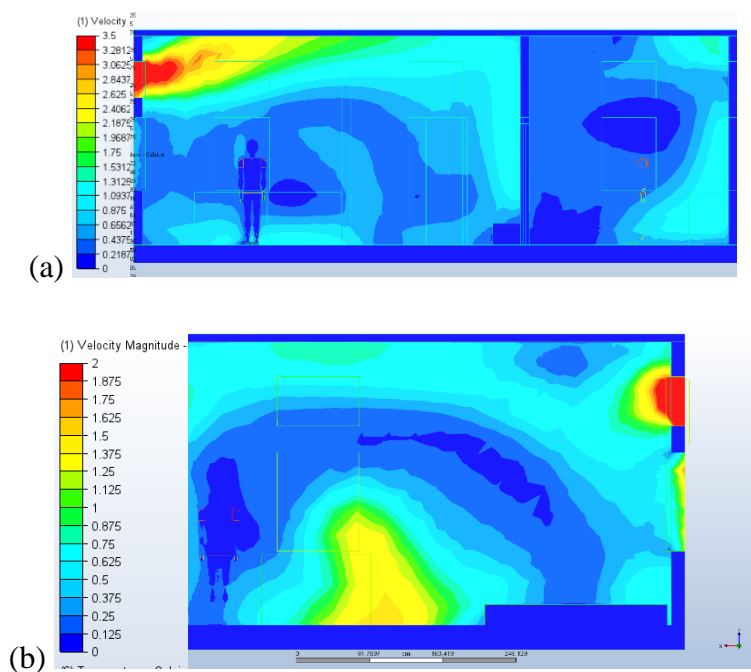


Figure 5. Overall air velocity distribution in Johor

In Szombathely, *Figure 6* illustrates the airflow pattern, which reveals a more directional and intensified flow, especially on the right-hand side of the building. The vector lines in this region are denser and more aligned, indicating strong, uninterrupted airflow, likely due to favourable wind entry and exit paths. In contrast, the left side of the building exhibits more dispersed and slower airflow, with several vortices and recirculation zones forming in corners and near walls. These circular patterns indicate areas where air movement is less effective, possibly leading to stagnant zones or uneven ventilation. *Figure 7* experiences stronger winds, causing airflow velocities of 0 to 5 m/s inside the building, as shown in (a) and 0 to 2.5 m/s in (b). The dynamic airflow is characterised by higher velocities and turbulence. The stronger winds enable greater exchange of indoor and outdoor air, which enhances NV and provides more cooling and better temperature regulation. Higher air velocities, especially when occupants have some control over their environment, can significantly improve thermal comfort by increasing convective heat loss. In this case, the stronger winds facilitate a greater exchange of indoor and outdoor air, thereby enhancing NV effectiveness and inducing better temperature regulation and cooling, which is particularly beneficial in hot and humid climates. Nonetheless,

areas experiencing wind speeds near or above 5 m/s should be carefully evaluated to avoid discomfort from drafts.

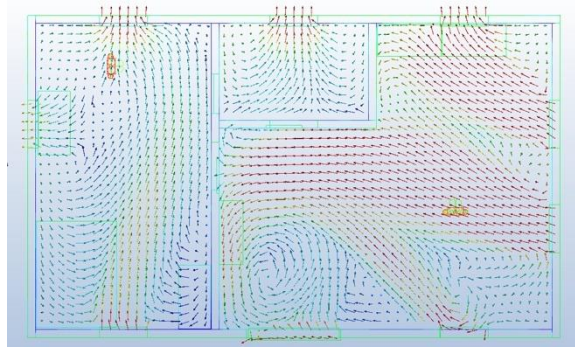


Figure 6. Overall air circulation in Szombathely

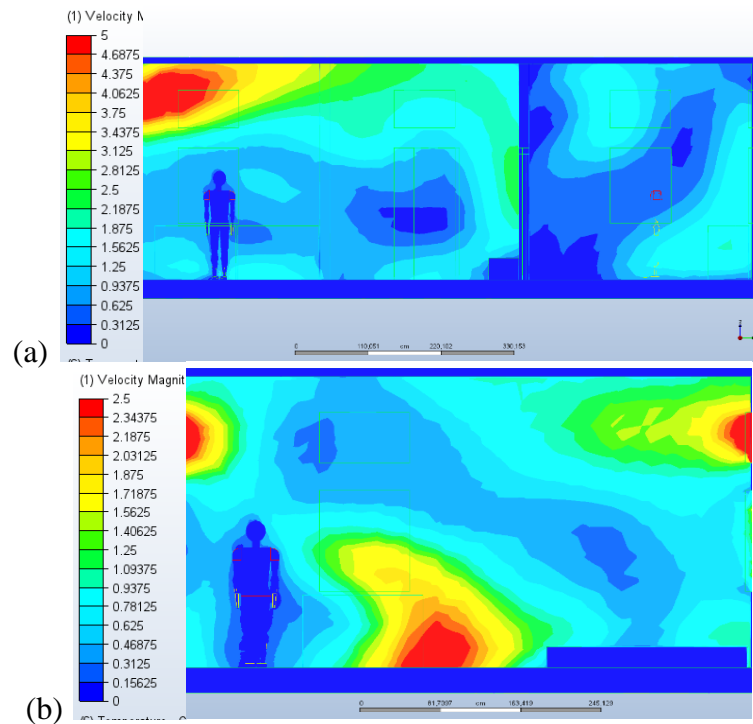


Figure 7. Overall air velocity distribution in Szombathely

The graph in *Figure 9* compares the velocity magnitude (m/s) against the distance from Point A to Point B, shown in *Figure 8*. In Johor, the airflow velocity remains low and steady, below 1 m/s for most of the distance. In Szombathely, the airflow starts higher (around 2.5 m/s) and remains consistently higher, indicating more efficient ventilation and cooling, especially during extreme temperatures.



Figure 8. Point A and Point B plotting

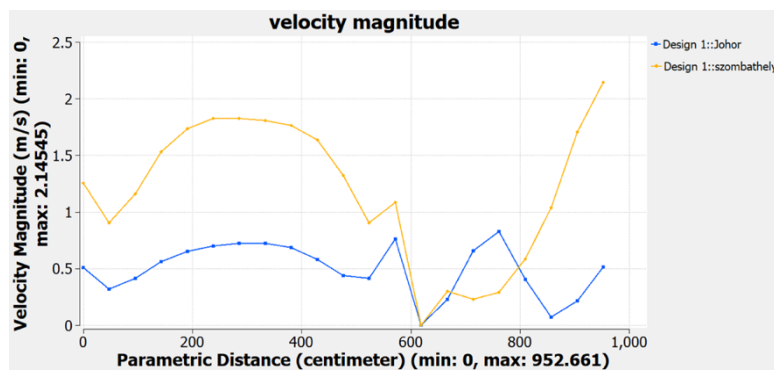


Figure 9. Change of velocity magnitude along the path from point A to B

### 3.2 Flow Dynamics and Air Circulation

Figure 10 and Figure 11 provide velocity vector representations of the airflow dynamics. In Johor, wind velocities range from 0 to 0.6 m/s around the human figures, suggesting a steady but moderate airflow. In Szombathely, the airflow around the two human figures ranges from 0 to 2 m/s, indicating a more dynamic circulation and better penetration of airflow throughout the building. The increased wind speeds in Szombathely lead to more effective cooling and improved thermal comfort compared to Johor, where moderate wind speeds result in more stable but less dynamic airflow.

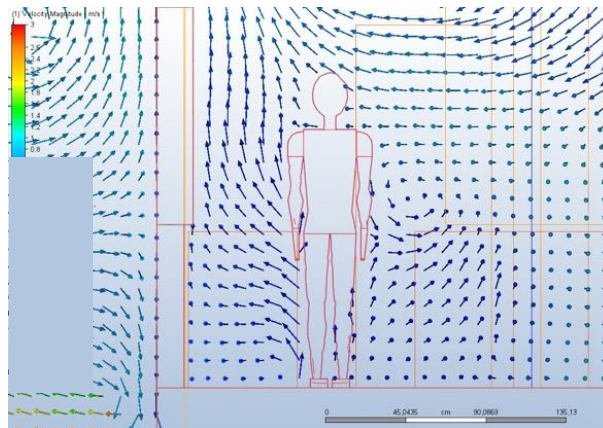


Figure 10. Air circulation near human figures in Johor

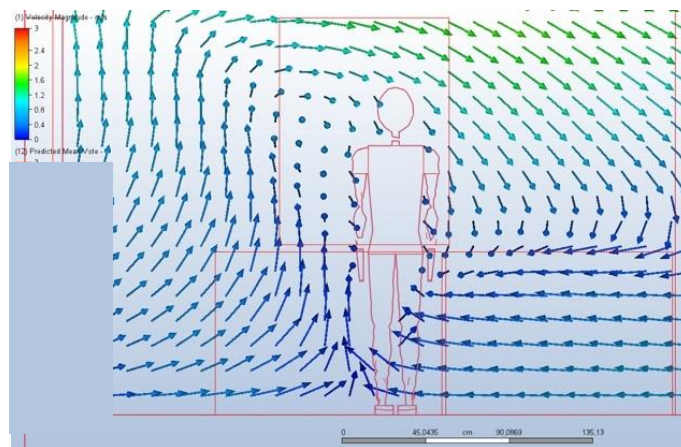


Figure 11. Wind circulation near the human figure in Szombathely

While the woodcarving ventilation panels help improve airflow and passive cooling in both Johor and Szombathely, the extreme temperatures in both locations remain a significant challenge to achieving optimal thermal comfort. Passive ventilation alone may not be sufficient to address these extreme conditions. Integrating HVAC systems can help supplement passive cooling by providing active cooling and dehumidification. In Johor, HVAC systems can enhance cooling during the hottest months, while in Szombathely, they can help maintain comfortable indoor temperatures during high outdoor temperatures, supporting the effectiveness of the NV system.

#### 4 DISCUSSION

The integration of passive NV, particularly through traditional woodcarving elements, plays a significant role in maintaining thermal comfort in buildings (Jay et al., 2023; Nugroho, 2024), especially in climates with moderate temperatures. However, as observed in the Johor and Szombathely case studies, passive airflow alone does not suffice to maintain optimal comfort in conditions where the indoor temperature exceeds 34°C, which falls outside the acceptable range defined by ASHRAE Standard 55 for naturally ventilated spaces. This highlights the limitation of relying solely on passive design strategies in both tropical and temperate climates (Alkausar – Riyani, 2023).

Although high wind speeds are generally beneficial for NV, this study treats the combination of high wind speed and high temperature as a worst-case scenario for thermal comfort due to potential draft discomfort and elevated heat gains in extreme conditions. This can cause sensations such as discomfort from still, humid air or excessive draft, depending on airflow direction and velocity. By connecting airflow performance to user sensations as described in ASHRAE 55, such as air movement acceptability and occupant satisfaction, a fuller picture of the thermal experience emerges (Candido – Dear, 2012). Moreover, the interaction between airflow and characteristics and human comfort is complex. Factors such as airflow velocity, turbulence, and the spatial arrangement of ventilation openings significantly influence user perceptions of comfort (Sholanke et al., 2022). For example, in areas where airflow is inadequate or overly turbulent, occupants may experience discomfort in the form of stickiness, draft discomfort, or lack of cooling, which detracts from the intended benefits of NV. Therefore, a more detailed understanding of how these airflow characteristics are perceived by occupants is necessary for optimising NV systems in future designs.

Beyond thermal comfort, the use of traditional woodcarving for ventilation serves both cultural and functional roles (Haoming – Chen, 2014; Ayowembun – Arifin, 2024). From a

modern user's perspective, the aesthetic value of these features can be preserved while improving thermal performance. This balance between tradition and comfort is crucial for integrating heritage elements into contemporary sustainable architecture.

## 5 CONCLUSIONS

This study concludes that passive ventilation using traditional woodcarving panels is insufficient to maintain thermal comfort as defined by ASHRAE standard 55, particularly during periods of extreme summer heat in both study regions. A hybrid strategy combining HVAC systems with traditional architectural elements is therefore recommended to achieve comfort standards. Importantly, the refinement of traditional elements should not only focus on preserving cultural identity but also on enhancing performance. Integrating modern design tools and engineering principles can improve airflow delivery and contribute to occupant well-being while retaining the symbolic and historical essence of traditional craftsmanship (Laine et al., 2000; Lyckov, 2024). In conclusion, the effective integration of traditional and modern systems offers a promising path toward designing spaces that respect cultural heritage while meeting the thermal and comfort needs of contemporary users. This approach can help create more sustainable, culturally sensitive and comfortable living environments, both for the present and future generations.

## 6 FUTURE CONSIDERATIONS

The integration of traditional design elements with modern HVAC systems offers a promising area for further research. Future studies could explore how traditional architecture can be future-proofed by combining eco-friendly HVAC solutions with local materials, ensuring both sustainability and thermal comfort. Consider the broader implications of cultural heritage preservation in modern-day buildings and propose further research into efficient solutions that balance cultural identity with comfort.

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# Environmental Attitudes of Firewood Users in Hungary: Contradictions of Knowledge and Emotions



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## ABSTRACT

This study examines environmental attitudes toward the production and utilization of firewood. A telephone survey using a structured questionnaire was conducted. The survey yielded 603 usable responses, and the analysis revealed that firewood users exhibited strong support for two fundamental environmental concepts: the notion that harvesting firewood from healthy trees is acceptable and the assertion that firewood is, in principle, carbon-neutral. However, a significant proportion of respondents also expressed concerns that firewood use may potentially contribute to forest degradation and increase climate change. To further explore these attitudes, respondents were categorized into three distinct groups. A statistical analysis revealed significant differences among these groups in educational attainment and standard of living. Attitudes towards complex environmental issues are predominantly influenced by emotions that reflect general environmental concerns due to the public's limited knowledge base, which hinders factual assessments.

## TANULMÁNY INFÓ

### Kulcsszavak:

Szolgáltatások  
fenntarthatósága  
Körforgásos gazdaság  
Karbonsemleges  
Szénciklus  
Éghajlatváltozás  
Fa tüzelőanyag  
Fatüzelés

## KIVONAT

**A tűzifát használók környezeti attitűdje Magyarországon: A tudás és az érzelmek ellentmondásai.** A jelen tanulmány a tűzifa termelésével és felhasználásával kapcsolatos attitűdöket vizsgálja. Telefonos felmérést végeztünk, strukturált kérdőív segítségével, amelyből 603 felhasználható válasz érkezett. Az elemzés kimutatta, hogy a tűzifát használók két alapvető környezetvédelmi koncepciót támogatnak: azt, hogy a tűzifa egészséges fákról való kitermelése elfogadható, és azt, hogy a tűzifa elvileg szén-dioxid-semleges. A válaszadók jelentős része azonban aggodalmát fejezte ki amiatt is, hogy a tűzifa felhasználása potenciálisan hozzájárulhat az erdők degradációjához és fokozhatja az éghajlatváltozást. Ezen attitűdök további feltárása érdekében a válaszadókat három különböző csoportba soroltuk. A statisztikai elemzés jelentős különbségeket tárt fel a csoportok között az iskolai végzettség és az életszínvonal tekintetében. Az összetett környezeti kérdésekkel kapcsolatos attitűdöket túlnyomórészt az általános környezeti aggodalmakat tükröző érzelmek befolyásolják, ami a lakosság korlátozott tudásbázisának köszönhető, ami akadályozza őket a tényyszerű értékelésben.

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## 1 INTRODUCTION

Woody biomass plays a significant role among renewable energy sources in Europe, which the recent energy crisis has underscored (Carnia et al., 2020; Kožuch et al., 2023). Firewood is a vital heating source in Hungary, used by 1,398,278 households, representing a 31% share of all households. It is the second most common home heating fuel after natural gas (Central Statistical Office, 2022).

This study focuses on three aspects of firewood use. First, as a traditional energy source, it is produced in large quantities. Consequently, it contributes to the economic output of forestry significantly and plays a crucial role in the energy supply. Second, wood harvesting from forests induces concerns that production can lead to environmental disturbances or even permanent degradation. Third, wood combustion is often associated with air pollution even though firewood is renewable and its carbon cycle is almost completely closed. *Table 1* summarizes the above-listed aspects.

*Table 1. Examined aspects of firewood use*

	Production	Consumption
Contribution to the economy	Added value to the regional economy	Energy security improvement through diversification
Environmental impacts	Forest disturbance	Air pollution
Regulatory effects	Circular carbon-flow Competition to other wood products serving as carbon pools	

Forests are vital natural assets, and their utilization increases the added value in the regional economy. Exploiting this economic potential is crucial in rural areas where economic activity is lower than in urban areas (Huttunen, 2012). The availability of other energy sources, such as natural gas, coal, and electricity, influences firewood demand and prices (Trømborg et al., 2008). Beyond that, regional and national energy security heavily depends on a diversified energy mix (Ladanai and Vinterbäck, 2009; Mydlarz et al., 2024). The energy crisis caused by the Russian-Ukrainian war revealed the importance of adaptability (Balmaceda et al., 2024). The crisis caused the prices of various energy sources, including gas, crude oil, and coal, to surge (Zaid and Farooque Khan, 2023), instigating a shift in household heating preferences in Hungary (Tóth et al., 2024). Rising natural gas prices may increase reliance on firewood because the choice between the two most common heating options primarily depends on relative costs (Csuvár, 2019).

Rising firewood prices increase competition in paper, wood, and fiberboard markets, which is a significant economic consideration (Nepal et al., 2019) because industrial utilization generates larger added value. Such utilization also provides opportunities for longer-duration carbon content storage, thereby creating or maintaining a carbon pool (Király et al., 2019).

An advantage of firewood is that it contains carbon sequestered from the atmosphere, and its continuous production by sustainable forest management maintains a closed carbon cycle. Other alternatives, especially fossil fuels, entail permanent carbon dioxide emissions (Matthews and Robertson, 2001; Pierobon et al., 2015; Jayakrishnan et al., 2022). Under a constant environment, all energy and matter circulating between the forest and its environment through its natural processes are in balance in the long run. The carbon cycle is no exception. A very

low rate of carbon accumulation is observable in the soil. Firewood production does not disturb this cycle. On the contrary, it allows us to access the stored energy that the decomposition of organic matter would have released, all without benefiting humans.

Although the energy flow of forests can serve human interests, forestry activities disturb the natural process regardless of their intensity (Bouget et al., 2012). Firewood production necessarily decreases the amount of deadwood (Bölöni et al., 2017), which inevitably affects the ecosystem. Forestry practices of lower technical standards can have more significant consequences, such as degradation of tree species composition and vertical structure, micro-habitat loss, and soil damage. In extreme cases, the whole ecosystem can be damaged when forests are converted into tree plantations and their maintenance requires active management.

The most significant environmental effect of firewood use is the release of smoke (Lipfert and Lee, 1985; Press-Kristensen and Tolotto, 2021). Wood burning can cause indoor and outdoor air pollution, which poses serious health risks, depending on the technology used (WHO 2015). According to a report by the European Environment Agency (EEA), 96% of the urban population in the EU is exposed to PM<sub>2.5</sub> concentrations that are harmful to health (Targa et al., 2024). The pollution may be severe if heating devices are unequipped with filters and/or the combustion is of low efficiency. The latter also depends on the moisture content of the wood (Price-Allison, 2019).

The above contradictions concerning the benefits of firewood production cannot be fully resolved. Research on the shaping of environmental attitudes and behavior by personality traits, emotional intelligence, knowledge, and social context, among other factors, has highlighted knowledge as the most effective predictor. Individuals with a comprehensive and profound understanding of environmental issues are more likely to demonstrate environmentally conscious behaviors. (Hadler et al., 2022; Ienna et al., 2022) Other studies claim that although knowledge has no significant direct effects on pro-environmental behaviors, it is a key factor that creates a starting point in a chain of causation leading to positive environmental attitudes (Liu et al., 2020).

Some of the above issues are covered by the elementary and secondary education curriculum, others are the focus of public discourse and are well articulated by the media, while others remain within professional circles. Therefore, different societal groups possess varying levels of knowledge. Coupled with dissimilar levels of susceptibility and interest, this results in a wide range of attitudes towards these issues. This study aims to reveal how firewood users, who are expected to understand the direct benefits of wood utilization, think about relevant environmental issues and how they fill knowledge gaps with emotionally based beliefs. We extend this analysis by describing the environmentally friendly lifestyle choices of firewood users.

## **2 MATERIALS AND METHODS**

### **2.1 The field of study**

A questionnaire survey was conducted to assess the attitudes of firewood users in settlements outside the capital and county towns of Hungary. *Figure 1* shows the number of samples by county. Residents of the capital and the county towns were excluded from the survey. According to the 2022 census of the Central Statistical Office—only 2 % and 9 % of the residences using firewood are located there, respectively. Wood combustion is, therefore, more common in rural areas in Hungary, with 55 % of homes using firewood in villages and 34 % in small towns (Central Statistical Office, 2022).

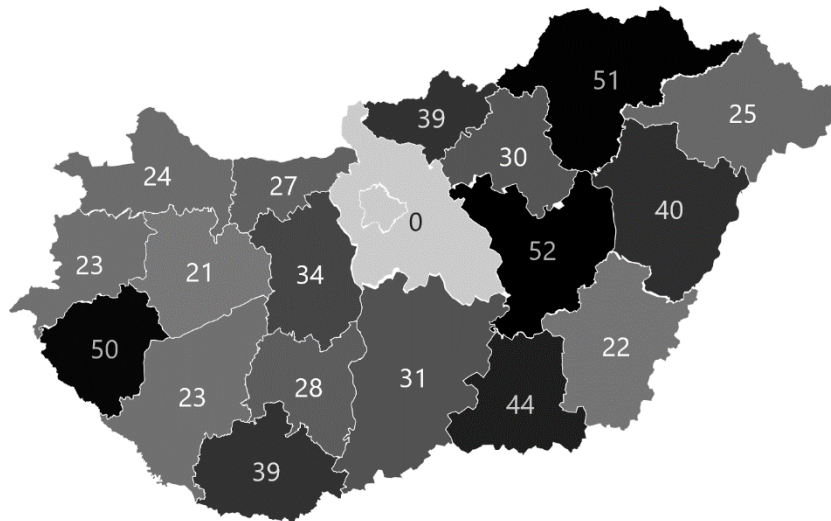


Figure 1. Sample distribution over the counties of Hungary

## 2.2 The survey

The questionnaire survey was conducted by M.A.S.T. Market and Public Opinion Research Company employing the C.A.T.I. (Computer Aided/Assisted Telephone Interview) methodology. The survey sample comprised adults with Hungarian citizenship residing in Hungary who have at least a partial reliance on firewood for their household energy needs. The survey yielded 603 usable responses, but systematic answers were excluded in some questions. It is vital to note that some of the questions in the questionnaire referred to the household as a whole and activities that are not necessarily performed by the respondent but by someone else in the household. Further questions, such as attitude questions, referred to personal beliefs and thoughts. While national statistics on households exist, no data on the demographics within households that use firewood is available. Thus, the representativeness of attitude questions cannot be assessed.

## 2.3 Data protection

Participation in the survey was voluntary, and respondents got no reward of any kind. Responses were recorded anonymously by the market research company; therefore, the authors did not need to handle personal information.

## 2.4 The questionnaire

The questionnaire consisted of 25 questions regarding firewood use habits covering the purpose of use, household energy infrastructure, procurement, handling, storage, and attitudes toward broader sustainability and environmental aspects of firewood use. Respondents can be characterized through nine demographic questions, including age, gender, education, type of residence, household size, and income. All questions were direct, closed-ended questions seeking numerical answers, choosing from the predefined options, or evaluating the question on a Likert scale. For some questions, optional answers included 'other,' and respondents could specify what 'other' meant in their cases.

The present study examines the survey results on attitudes and habits of firewood users regarding the environmental aspects of firewood use. Questions about attitudes were formulated in a broader sense so that they refer more to feelings than knowledge.

## 2.5 Methods used in the analysis

Responses were evaluated after excluding ‘don’t know’ and ‘no answer’ results. Schematic answers were also excluded in Likert-scale questions. Consequently, the sample size varies from question to question and is indicated in each case.

Demographic differences between attitude groups of firewood users were tested with the Kruskal-Wallis test.

## 3 RESULTS

### 3.1 Demographic description of the sample

The respondents were mostly (73 %) above 51 years of age, while the younger generation, between 18 and 30 years, represented only 7 % of the sample. A slightly higher proportion of women than men participated in the survey (58 % vs 42 %). The majority (67 %) of respondents live in villages, and 33 % live in towns. In terms of education, the majority (67 %) of respondents cited secondary-level education, including apprenticeships and graduation, while those with higher and elementary education totaled 14 % and 18 %, respectively.

Table 2. Demographic data of the respondents

<i>Age:</i>				
18–30 years: 7 %	31–50 years: 19 %	51–65 years: 33 %	Over 65 years 40 %	No answer: 1 %
<i>Sex/Gender:</i>				
Female: 58 %			Male: 42 %	
<i>Location of residence:</i>				
Town: 33 %		Municipality: 67 %		
<i>Highest completed level of education:</i>				
Elementary: 18 %	Apprenticeship: 31 %	Graduated: 36 %	Higher education: 14 %	No answer: 1 %
<i>Headcount of respondents' households:</i>				
1 person 23 %	2 persons: 31 %	3 persons: 16 %	4 people 20 %	5+ persons: 10 %
<i>Percentage of respondents with at least one child in the household:</i>				
Yes: 38%			No: 62%	
<i>The financial situation of respondents:</i>				
Paycheck to paycheck:  25 %	Monthly expenses can be covered if no major expenditures occur: 48 %	Savings can be made over monthly expenses:  19 %	No answer:  7 %	

The size of the households represented in the survey showed an even distribution: 23 % were single-person households, 31 % were two-person households, while three, four, and five and more-person households were 16 %, 20 %, and 10 %, respectively. Households with non-earning children accounted for 38 %. Households that could only barely cover their monthly expenses (paycheck-to-paycheck) totaled 25 %. Households that could cover monthly expenses provided there were no unexpected large expenditures amounted to 48 %. Only 19 % indicated that their incomes allow them to save money. *Table 2* summarizes the demographic characteristics of the sample.

### 3.1. Attitude toward environmental aspects of firewood use

Our approach in this study treats the attitude toward firewood use as a mixture of knowledge and feelings with more emphasis on the latter. Knowledge covers facts and processes that together provide a basis for forming an opinion. The certainty and depth of knowledge of a non-professional do not allow for a clear and objective comprehension of the subject matter. Thus, panel arguments and impressions from public discussions can considerably influence opinions. Over time, these opinions can settle into attitudes.

The questionnaire included four statements regarding the environmental aspects of firewood production and use. The respondents were asked to indicate their level of agreement or disagreement with these statements on a 5-point scale. The statements were presented in a random order. Some were positively formulated, while others were negatively formulated.

One statement specifically targeted whether tree harvesting is acceptable if done sustainably (S1: 'A healthy tree can be harvested for firewood in the frame of sustainable forestry that entails replanting.') S1 eliminates the possibility that tree felling is rejected because it could potentially lead to deforestation and reinforces this by specifically mentioning replanting for those who are unfamiliar with the term 'sustainability.'

Another specific statement referred to the carbon-neutral nature of firewood. (S2: 'Firewood is a carbon neutral (environmentally friendly) energy source since the trees that have been cut get replanted by the foresters.') Carbon neutrality is a complex concept that cannot be evaluated without a basic understanding of underlying processes and their interrelations. Therefore, the questionnaire included a summary of the essence of carbon neutrality to avoid responses based on misinformation or misconceptions.

A more general statement is required to assess whether the use of firewood will harm forests (S3: 'The use of firewood for heating poses a significant threat to the forests of Hungary and their ecosystem'). This statement covers at least two mechanisms that potentially influence the state of forests. First, firewood production can directly degrade forests and forest ecosystems. This aspect is closely related to S1, which focuses more on acceptance, while S3 is asking about consequences. Consequences could be evaluated separately to the wood production potential and the natural state of the ecosystem. A detailed analysis would also separate the effects on natural forests and plantations. The second line of arguments covers the environmental effect of firewood use, most importantly air pollution, and its effect on forests. This complex statement could have been separated by these mechanisms, but then we would have received answers about the knowledge of the respondents and less about their attitudes.

The fourth statement investigated the effect of firewood use on climate change (S4: 'The use of firewood for heating significantly increases climate change.'). Similarly to S3, firewood use may have an impact on disturbing the carbon cycle on the harvest side and through air pollution. In the latter case, fumes from firewood combustion can be considered carbon emissions. Furthermore, air pollution, as a negative impact on the environment, can be falsely associated with climate change.

The first two statements (S1 and S2) attempt to narrow down the subject and reduce the possible role of misinterpretation of key terms. The latter two (S3 and S4) address complex

concepts that are more likely judged by feelings and impressions rather than reason. Furthermore, there is a strong relationship between S1 and S3 as well as between S2 and S4, as S1 and S2 address core elements of the complex mechanisms behind S2 and S4.

Table 3. Responses to statements regarding the environmental aspects of firewood use (n=586)

Statements	Strongly agree 5	Rather agree 4	Agree/ disagree 3	Rather disagree 2	Strongly disagree 1	avg.	I do not know	No answer
S1: A healthy tree can be harvested for firewood in the frame of sustainable forestry that entails replanting.	34 %	33 %	15 %	9 %	6 %	3.7	2 %	0 %
S3: The use of firewood for heating poses a significant threat to the forests of Hungary and their ecosystem.	22 %	27 %	26 %	14 %	7 %	3.3	4 %	0 %
S2: Firewood is a carbon-neutral (environmentally friendly) energy source since the trees that have been cut get replanted by the foresters.	47 %	27 %	15 %	4 %	0 %	3.9	7 %	1 %
S4: The use of firewood for heating significantly increases climate change.	12 %	26 %	2 %	18 %	12 %	2.8	7 %	1 %

Table 3 summarizes the responses to the above-described statements. 67 % of respondents agree that even a healthy tree can be cut for firewood (S1), while 15 % reject the idea. There is also a clear majority (74 %) that agree on the carbon-neutral nature of firewood (S2). Only 4 % disagree with this statement.

Despite the divergent opinions regarding S1, 49 % of respondents believe that forestry is threatened by firewood production. Only 21 % deny this assertion. A similar trend is evident in the case of S4, where 38% of respondents consider firewood heating to be a significant contributor to climate change, while 30 % hold a contrary view.

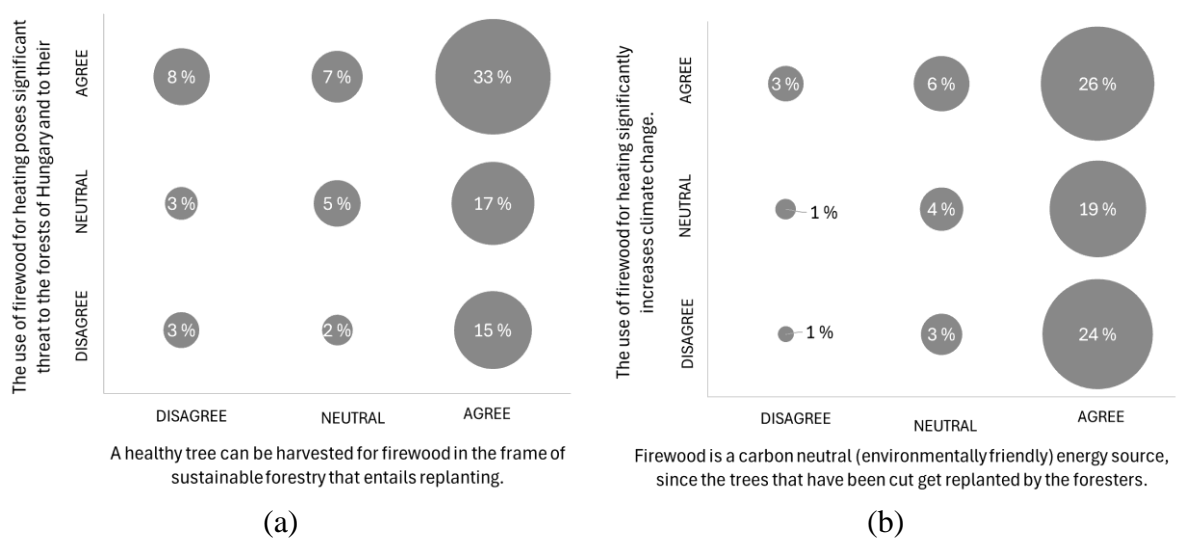


Figure 2. Contingency tables of environmental aspects of firewood production and use (a) Pair-wise adjudication of S1 and S3 (b) Pair-wise adjudication of S2 and S4

As *Figure 2* illustrates, 33 % of respondents concur with the view that harvesting healthy trees for firewood is a threat to forests, while 16 % disagree, asserting that firewood use does not pose a threat to forests. The results are very similar in statements about firewood as a carbon-neutral energy source and that its use increases climate change, as these statements are supported by 26 % of the respondents. 24 % of the respondents think that firewood is a carbon-neutral energy source and that its use does not increase climate change.

### 3.2 Characterization of respondents according to their general attitude toward firewood

Survey participants who gave 1–5 responses to all four statements (S1–S4) were classified into three groups. Participants who chose ‘I do not know’ or ‘No answer’ to any of the four statements were excluded from the classification. Those responding ‘Agree/disagree’ to all four statements were also excluded. Altogether, 477 respondents remained in the sample.

The first group, ‘Firewood supporters,’ consists of people who see firewood positively or neutrally in all four questions. They responded 5-3 to S1-S2 and 3-1 to S3-S4.

The opposite group is called the ‘Firewood critics,’ formed from those who expressed negative opinions consistently by responding 3-1 to S1-S2 and 5-3 to S3-S4.

The rest of the respondents are classified as ‘Miscellaneous.’ Here belong those who have at least one positive and at least one negative opinion on the environmental effects of firewood production and use.

Statements	Strongly agree 5	Rather agree 4	Agree / disagree 3	Rather disagree 2	Strongly disagree 1	I do not know	No answer
S1	Supporters			Critics			
S2							
S3	Critics			Supporters			
S4							

*Figure 3. Criteria of classification of the respondents*

*Figure 3* summarizes the classification criteria. The size of the above categories was:

- Firewood supporters: 148
- Miscellaneous: 309
- Firewood critics: 20

We examined whether there were differences in demographic characteristics between respondents of the three different groups. For this purpose, a nonparametric test, the Kruskal-Wallis test, was used because not all dependent variables have a normal distribution.

As *Figure 4* shows, education and living standards were found to be significantly different between the three groups. Education among Supporters is higher than among Miscellaneous and Critics. A similar, but not entirely the same, phenomenon can be observed in the case of living standard, as Supporters have a higher living standard than Critics, but Miscellaneous have even higher.

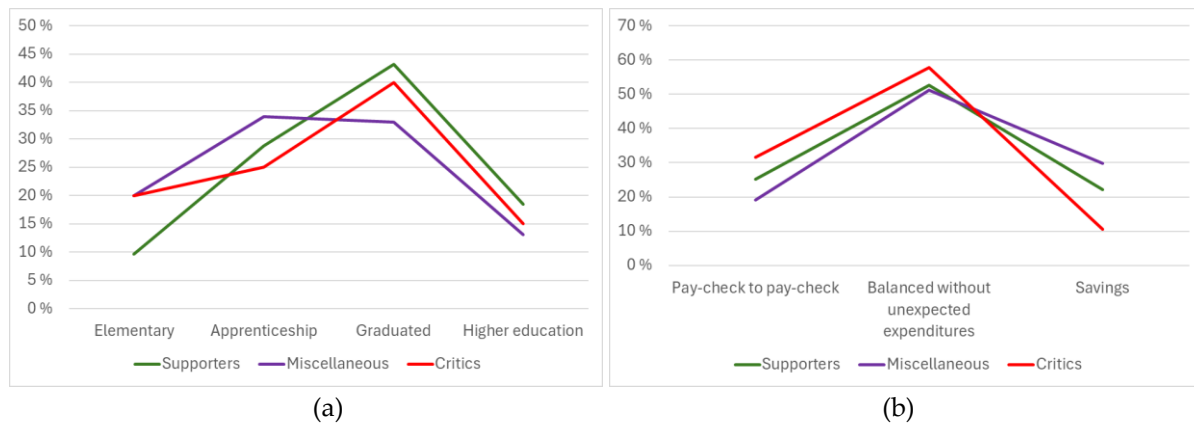


Figure 4. Demographic differences between attitude groups. (a) Distribution of respondents over education categories (b) Distribution of respondents over living standard categories (c) Results of the Kruskal-Wallis test (N values vary according to the demographic data availability).

### 3.3 Environmental awareness of respondents

The survey included a series of statements about lifestyle choices and habits that either symbolically or meaningfully contribute to environmental protection. Respondents were asked to rate these statements on a 5-point scale according to how typical each was for them. *Figure 5* details the results.

Selective waste collection is the most supported item on the list (93 % combined agreement), closely followed by eating local food (90 %) and well behind avoiding plastic packaging (66 %). Although the former is indeed common in Hungary, it is unclear how local 'food source' was understood and what role local food plays in the diet of the supporters. There may have been some confusion between local grocery stores and local food sources.

Another group of statements relates to alternatives to car use. Walking and cycling instead of driving are supported by a slight majority (55 % and 52 % respectively), while public transport is only supported by 39 %. Given that the survey was conducted in rural areas and in small towns, these answers make perfect sense, as short distances allow walking and cycling, while public transport is only available for commuting to nearby cities, which affects only a part of the population.

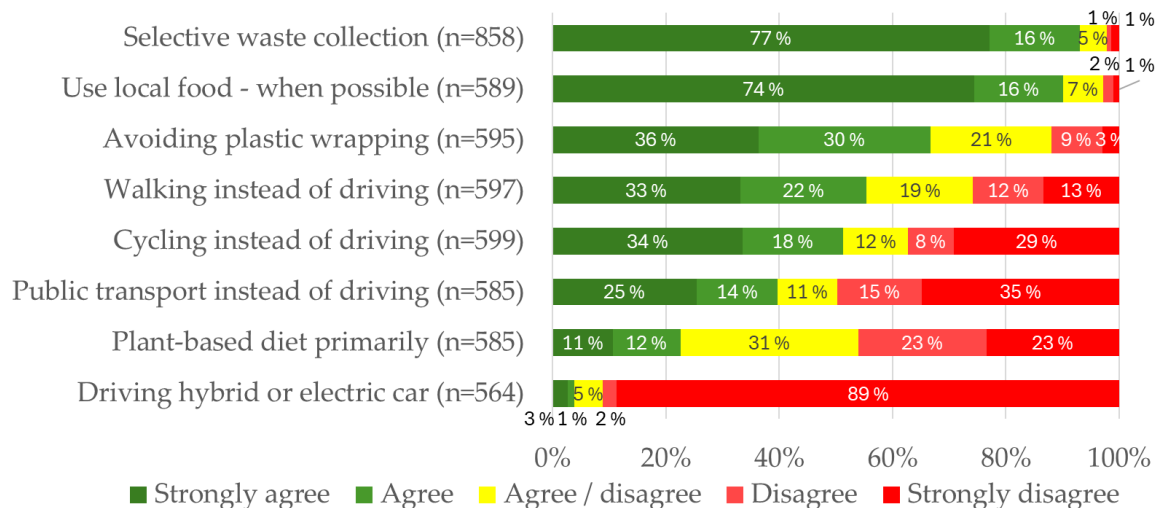


Figure 5. Habits and lifestyle choices with environmental considerations

The least supported statements are a plant-based diet (23 %) and driving an electric car (4 %). The latter has an overwhelming rejection (89 % strongly disagree), which is probably a clear reflection of the low share of electric and hybrid cars in rural areas. Although it is coupled with the highest share of neutral answers (31 %), the low support for a plant-based diet is surprising in comparison to the strong support for local food sourcing. The reason for this balanced distribution of responses may be that, apart from vegetarian and vegan diets, it is difficult to objectively assess how much of a diet is plant-based.

## 4 DISCUSSION

### 4.1 Firewood users

Firewood is produced in 1 m or 2 m lengths and less than 50–60 cm in diameter. The moisture content depends on the season and species. Firewood processing includes cutting and splitting, which are rather noisy and dirty and require space. Wood should be dried for at least a whole summer before combustion. All these requirements and circumstances determine that firewood is used more in less urbanized regions. Ready-to-use firewood can be a solution in cities to the above inconvenience, but only if it is a supplementary energy source because of the lack of storage space that can cover all energy needs for heating, hot water, and cooking. For this reason, firewood use in large cities has been phased out since the advent of natural gas. Currently, 92% of dwellings in the capital and county cities are heated with gas or electric appliances in individual or district heating systems (Central Statistical Office, 2022). In heavily populated areas, air pollution is another argument against all solid energy sources, including wood.

Based on the reasoning above, the study targeted firewood users living in villages and small towns, and the sample evenly covers all parts of the country. The survey's representativity cannot be tested because of the lack of demographic data for the whole population. Nevertheless, important insights can be gained about the attitudes toward firewood and its environmental impacts.

One of the results of this survey is that the dominant user group of firewood lives in households of 1 or 2 people, typically without children.

According to official statistics and related studies (Bajomi et al., 2022; Kármán-Tamus and Pálvölgyi, 2022), firewood use in Hungary is most common among the poorer, rural population.

The social, environmental, and economic sustainability of life in rural small settlements depends on many factors where income status plays a significant role (Szlávik – Csete, 2004). Such information is sensitive and private. Therefore, the questionnaire included only general questions regarding the living standard. The results show that the majority of firewood users are living in a balanced financial situation.

## **4.2 Environmental attitude**

This survey was an initial attempt to reveal how attitudes toward firewood are constructed from elements of knowledge and emotions. Although firewood users are not directly involved in firewood production, their insights about firewood use may allow for more balanced views than what we can expect from outsiders.

Answering attitudinal surveys is challenging for the respondents because they are asked to make judgments about complex issues in a relatively short time. In such situations, respondents rely on their pre-existing knowledge or their emotions, making it difficult to assess the responses and uncover underlying motives and causations. However, public attitudes can have a strong influence on various policies. Therefore, they will shape future forests and forestry.

The most accepted (74 %) claim by far was that firewood is carbon neutral. This seems to be a more widely embedded view in society. Harvesting a healthy tree for firewood is acceptable to the majority of respondents (67 %), provided a seedling or sapling is planted to replace it. These results represent situations where a simple environmental concept worded reassuringly and explained well helps gain acceptance.

At the same time, a large proportion (49 %) of the respondents consider firewood use as a serious threat to the forests and their wildlife. Similarly, a smaller but significant proportion (38 %) believes that firewood use increases climate change. Although responses to the effects of firewood on climate change are evenly distributed, they contrast with the answers on carbon neutrality. These results represent situations when a more complex environmental issue, presented without reassuring or explanatory elements, allows more room for emotions and preconceptions.

For the contradictions between the views on a complex concept and its principle, at least four possible reasons can be identified:

- Respondents express a well-grounded opinion and agree with the basic concept, but due to other factors, the related broader concept is not valid, and they disagree with it.
- The wording of the core concepts is more assuring and tries to avoid misinterpretation, while the complex concept is presented without any additional information that could help the interpretation.
- The respondents have little knowledge about the complex concept. They might not realize the relationship between the concept and its fundamental principle, and their answers are more based on feelings and impressions.
- The respondents tend to agree on whatever question they are asked in a questionnaire.

Sustainable forest management is regulated by law in Hungary, and the forest area is increasing. However, the image of Hungarian forestry that respondents hold may be starker than reality. In theory, they agree with the idea of harvesting forests for firewood, but they do not perceive the necessary conditions for this, namely sustainable forest management. This is also linked to the acceptance of carbon neutrality, which is based on the continuous forest cycle and carbon sequestration. There could be a lack of confidence that what works in theory is implemented in practice, i.e., emitted carbon is sequestered. In a national-level representative opinion poll conducted a few years ago, the majority of Hungarians did indeed think that the forest area in Hungary was decreasing. In addition, many people believed that the condition of

forests had even gotten worse (Lomniczi, 2017). The energy crisis caused by the Russian-Ukrainian war has led the Hungarian government to proclaim many measures related to firewood production, trade, and public supply. The government decree was heavily criticized by conservation NGOs and the media (Lett – Hegedűs, 2024). Many articles defending Hungarian forests and sustainable forest management against the firewood decree have reached the public through the mass media. The effects of these could be reflected in the results presented.

However, carbon neutrality does not necessarily mean climate neutrality, not even in the scientific literature (Serman et al., 2022). Respondents may also have thought that burning firewood hurts the climate in the short term because carbon is released into the atmosphere and sequestered only in the distant future.

The classification of the respondents showed that 31 % hold a positive opinion about the environmental impact of firewood use and expressed no negative responses. We call this group Firewood Supporters. Only 4 % of the respondents are on the opposite side, with no positive responses; hence, the name Firewood Critics. In between, with a 65 % share, is the largest group called Miscellaneous. This group offered mixed responses with at least one negative and one positive opinion.

Statistical analysis revealed that these groups differ significantly in terms of their level of education and standard of living. Firewood Supporters have the highest level of education, followed by the Firewood Critics and Miscellaneous group. This result may partly explain why the Miscellaneous group, the least educated group, gave contradictory responses.

The living standards of the groups under consideration also differ from one another, in descending order: Miscellaneous, Firewood Supporters, and Firewood Critics. Although the difference is proven by statistical probing, no evident link has been found to demonstrate how this influences the research results.

### 4.3 Environmentally conscious behaviors

Nationally representative surveys indicate that a significant proportion of the Hungarian population believes it is doing the right thing for the environment, even if it costs more money and time. Most agree that it is worth doing something for the environment, even if others do not (Schneider – Medgyesi, 2020). The population considers it vital to promote environmentally conscious lifestyles and conscious consumer behavior in society. They also consider it crucial to reduce the amount of waste generated and collect waste selectively (Borda et al., 2016). A positive trend can be observed in Hungarian society in the latter area between 1993 and 2019. However, fewer people are now willing to pay higher prices to protect the environment than in the past. Our survey of firewood users confirms the results of previous research. The majority of respondents avoid plastic packaging, collect waste selectively, and buy local food when they can. In this respect, therefore, Hungarian firewood users continue the attitudes of the rest of society. On other issues, the attitudes of our sample were already divided. On the other hand, transport issues may also be influenced by the characteristics of rural life, such as the varying quality of public transport or the number of electric charging stations. However, a plant-based diet would be a factor independent of place of residence, and the majority of our respondents do not pursue this. Incidentally, 39 % of Hungarians say they would reduce their meat consumption to reduce the negative impact of climate change. This is five percentage points below the global average (Ipsos, 2022). Although we did not ask the same question, 46 % of respondents in our survey are negative in this regard, while a further 30 % are more neutral.

If we examine attitudes toward matters other than heating, firewood users generally follow the environmentally friendly behavior of the Hungarian population as a whole. Of course, we must consider that respondents may try to present themselves in a positive light when asked

about environmental issues, resulting in a slightly more favorable picture of respondents' pro-environmental behavior than the reality.

## 5 CONCLUSIONS

This research provided additional evidence that attitudes toward the environmental effects of firewood production and use are determined by factual knowledge but also emotions. The more complex the issue and the less stable and detailed the knowledge, the revealed attitude tends to reflect the general environmental concerns and tends to result in contradictory opinions.

While opinions may be contradictory, firewood users generally hold a more positive view of the sustainability of firewood compared to negative perceptions.

The present research study allowed only a few attitude-related questions in a wide-focused survey, which must be considered when assessing the results. Therefore, in-depth analysis is required to gain more precise information concerning knowledge and knowledge gaps, the influence of public discourses, impressions, and personal emotions that play significant roles in shaping attitudes.

These results highlight the differences between public opinion based on sound knowledge and knowledge with gaps. The public is often involved in decision-making processes and policy formulation to gather information and take account of a wide range of interests. However, the public also validates such processes and increases acceptance of the results. Participatory processes should place particular emphasis on communicating the facts, processes, and broader context under the proposed outcomes so that stakeholders and the public have easy access to them.

These findings suggest that environmental issues should be integrated into primary and secondary education to allow the broadest possible range of society to learn about the issues and gain the knowledge needed to assess them. Moreover, environmental education for children outside school and information for the adult population should be further developed.

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## Guide for Authors

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## Contents and Abstracts of the Bulletin of Forest Science

Bulletin of Forest Science (Erdészettudományi Közlemények) is a journal supported by the Forest Research Institute of the Faculty of Forestry of the University of Sopron. The papers are in Hungarian, with English summaries. The recent issue (Vol. 14, 2024) contains the following papers. The full papers can be found and downloaded in *pdf* format from the journal's webpage ([www.erdtudkoz.hu](http://www.erdtudkoz.hu)).

### Vol. 14, Nr. 1, 2024

Tamás ÁBRI, Zsolt KESERŰ, Emese SÓVÁGÓ and Károly RÉDEI:

#### **Experiences of eastern white pine (*Pinus strobus* L.) crop management on sandy soil site conditions in the Trans-Tiszanian region ...5–14**

**Abstract** – The establishment of naturalisation attempts with the North American Eastern white pine (*Pinus strobus* L.) has a history of almost 60 years in Hungary. The ecological requirements of this species are balanced, humid climates and it is not suitable for establishing new afforestation under marginal site conditions. Eastern white pine stands established in the Trans-Tiszanian region, mainly near Debrecen, belong to yield classes IV and V based on the yield table of the Scotch pine (*Pinus sylvestris* L.). Their volume for a given age does not differ significantly from that of the Scotch pine stands. Eastern white pine stands mixed with northern red oak (*Quercus rubra* L.) and Scotch pine did not produce any surplus yield of practical importance. Even taking into account the negative effects of local climate change, the potential for the cultivation of Eastern white pine in the studied area is not promising.

<https://dx.doi.org/10.17164/EK.2024.01>

Atila BOROVIČS, Éva KIRÁLY and Péter KOTTEK:

#### **Predicting carbon balance in the Hungarian forestry and wood industry sector via the forest industry carbon model ...15–32**

**Abstract** – As forest-based climate change mitigation gains greater importance within international climate policy, understanding the mechanisms influencing the carbon offsetting capacity of the sector becomes increasingly important. Our study evaluates the climate benefits of contrasting forest management strategies: one focuses on reducing harvest and expanding forest carbon stocks, while the other aims to increase harvest to enhance carbon uptake, wood product carbon pools, and substitution effects. We analyse the carbon balance of the Hungarian forest industry under three scenarios: the business as usual (BAU) scenario with no changes in current harvest and afforestation levels, the extensification scenario with reduced harvest and afforestation levels, and the intensification scenario involving increased afforestation, improved wood assortments, and gradually increasing timber extraction which is still meeting sustainability criteria. We introduce the Forest Industry Carbon Model (FICM), a novel carbon accounting tool encompassing various carbon pools including forest biomass, dead organic matter, soil, harvested wood products, and emissions avoided through

product and energy substitution. Our findings indicate that the intensification scenario performs the highest net removals and optimized product and energy substitution effects. By 2050, the net carbon balance of the forest industry will reach  $-8,447$  kt CO<sub>2</sub> eq in the BAU scenario,  $-7,011$  kt CO<sub>2</sub> eq in the extensification scenario and  $-22,135$  kt CO<sub>2</sub> eq in the intensification scenario. Although substitution effects are not accounted for under the land-use, land-use change, and forestry (LULUCF) sector in Greenhouse Gas Inventories, emission reductions in the industry and energy sectors positively influence the national carbon balance. Our projections reveal that Hungary can meet the 2030 LULUCF greenhouse gas removal target set by EU legislation under the intensification scenario, necessitating significant innovation within the wood sector. In comparison, forest non-utilization proves to be a short-term solution, with its favourable effects diminishing by 2050 and leading to additional emissions as compared to the BAU scenario. This article is based on the original publication by Borovics et al. 2024 (Projection of the Carbon Balance of the Hungarian Forestry and Wood Industry Sector Using the Forest Industry Carbon Model).

<https://dx.doi.org/10.17164/EK.2024.02>

Attila FÁBIÁN, Ferenc LAKATOS, Veronika ELEKNÉ FODOR, Árpád ÓRSI, András NÁHLIK and András POLGÁR:

#### **Applied sustainability modell of the University of Sopron ...33–46**

**Abstract** – The University of Sopron has created the Sustainable University Model of the University of Sopron (SOE-FEM) based on its best practices, applying a systemic approach based on sustainability criteria. In the Institutional Sustainability Strategy, it defines its vision and SMART goals, for which it assigns an Implementation Program. Through university measures and work packages (WP), the model supports the implementation, operation and continuous development of the Sustainable University. The SOE-FEM is embodied in a pyramid model, with which we aim to create a university operating culture that treats sustainability as a priority and that can continue to spread in other sectors and in a wider social circle. Based on the Sustainability Strategy, the university announced the “Sound of Earth University of Sopron” Implementation Program (SOE-MP) under trademark protection. The implementation program of measures is in line with the UN Sustainable Development Goals (SDGs), and it provides a framework for the complex implementation and continuous development of the institutional sustainability culture. An essential element of the SOE-MP is the “University as a Living Lab Concept” roach.

<https://dx.doi.org/10.17164/EK.2024.03>

Gábor ILLÉS and Endre SCHIBERNA:

#### **Assessing afforestation potential on the basis of ecological datasets ...47–61**

**Abstract** – Within the framework of the Károly Kaán national afforestation program, we examined the change in afforestation potential in our country. During the tests, we used two climate change scenarios, based on the RCP 4.5 and RCP 8.5 emission forecasts. We determined the approximate size of areas that could be afforested in the future in the case of low-quality arable land, grassland or pasture land, and good-quality but steep arable land. We also examined how this opportunity changes over time. Areas that can be afforested sustainably were considered to be those whose soil is forest soil and/or which have an additional water supply available for the stands, and whose estimated potential for timber production reaches at least the 4th yield class. The results showed that currently approx. 456,000 ha of land may be suitable for afforestation may be among the low-quality arable land, but only 123,000 ha of this can be found on forest soils. Together with grassland and pasture areas, under similar conditions, this number can rise to 262,000 ha. However, as a

result of climate change, depending on the climate change scenarios, the proportion of areas suitable for afforestation decreases by at least 10 % every 30 years in the examined land use categories. In addition, the enforcement of nature conservation aspects results in a further area reduction.

<https://dx.doi.org/10.17164/EK.2024.04>

Éva KIRÁLY, Gábor KIS-KOVÁCS, Zoltán BÖRCSÖK, Zoltán KOCSIS, Péter KOTTEK, Tamás MERTL, Gábor NÉMETH, András POLGÁR and Attila BOROVIČS:

**Mitigating climate change through wood industry measures in Hungary ...63–86**

**Abstract** – Harvested wood products (HWPs) hold a significant amount of carbon, with long-lasting products and wooden buildings being some of the most effective methods for carbon storage. Extending the lifespan of wood products, along with proper waste management, recycling, and reuse, can further help meet climate goals. In our study, we projected the carbon storage, carbon dioxide, and methane emissions of the Hungarian HWP pool up to 2050 under 10 different scenarios to identify the combination of wood industry measures with the greatest impact on climate change mitigation. We utilized the country-specific HWP-RIAL model to forecast emissions related to the end-of-life and waste management of wood products. Our main finding is that without additional measures, the Hungarian HWP pool would turn from a carbon sink to a source of emissions by 2047. To ensure the Hungarian HWP pool remains a carbon sink, it is crucial to implement further climate mitigation strategies, including cascading product value chains and circular bioeconomy approaches. The most effective individual measures include increasing product half-life, boosting the recycling rate, and enhancing industrial wood production through increased assortments and harvesting. By combining these measures, an average annual climate change mitigation potential of up to 1.5 Mt CO<sub>2</sub> equivalents could be achieved during the 2022–2050 period. This article is based on the original publication by Király et al. 2024 (Climate change mitigation potentials of wood industry related measures in Hungary).

<https://dx.doi.org/10.17164/EK.2024.05>

Tamás KOLLÁR:

**Forest yield function and table of sessile oak (*Quercus petraea*) stands by the FRI's long duration research network database ...87–111**

**Abstract** – Yield table of sessile oak by the Forest Research Institute's long duration research network was publicised in 1981 by Albert Béky. Since then a great amount of data was accumulated from the University of Sopron – Forest Research Institute's (UOS – FRI) long duration forest yield and silvicultural research network by continuous recordings. From that database new yield functions and yield tables were made in favour of more accurate estimation of sessile oak yield. Altogether 1329 digitalised records from 243 parcels were processed, from that great differences were noticed compared to the previous tables. Besides making the traditional yield table, the methods of calculations were given in detail, from which a forest stand's individual growth trends can be calculated. The tables were made assuming a 100 % sessile oak mixture ratio, closure and density.

<https://dx.doi.org/10.17164/EK.2024.06>

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Anikó JAGODICS and Ernő FÜHRER:

**Investigations on leaf litter and humus layers of beech forests in Zala County (Hungary) in relation to weather conditions ...115–130**

**Abstract** – The amount of organic matter in leaf litter and humus layers, the changes in their carbon and nitrogen stocks over time, and their correlation with weather conditions were investigated in experimental plots of European beech (*Fagus sylvatica*) in Zala County, based on samples collected in 2006, 2010 and 2013. The mass of organic matter was the highest in the samples of 2006. The amount of humus decreased considerably by 2010 and then reduced further by 2013. Accordingly, the carbon and nitrogen stocks also decreased. The C/N ratio of humus showed a moderate increase over the years; however, the values indicated a favourable mull-type humus form every year. These changes in quantity and quality can be related to the weather from January to March between 2007 and 2010 which were milder and wetter than the long-term average. Based on the samples collected before and after the autumn litterfall in 2013, we concluded that a 27 % decrease in the amount of humus can occur even within two months. Compared to the long-term average, the higher average temperature and precipitation sum of October–November may have contributed to the decrease in organic matter as a result of the intensification of decomposition processes.

<https://dx.doi.org/10.17164/EK.2024.07>

Attila BENKE, Valter TOLDI, Tamás SÜLE and Katalin BEREZKI:

**Effects of fertilization on nutrient accumulation in black locust (*Robinia pseudoacacia* L.) leaves: results of an experiment in Tápiószele ...131–144**

**Abstract** – The basis of plantation forestry under often marginal environmental conditions is the use of varieties that can utilize the limited ecological conditions. In our research, the nutrient utilization capacity of different black locust clones (OBE01, OBE34, OBE53, OBE69) was investigated based on the nutrient content of their foliage. In the experimental plantation, which was established in poor sandy soil, different nutrient supplementation treatments were applied. Element utilization was evaluated based on leaf nitrogen, phosphorus, potassium, iron, manganese, copper, zinc and nickel contents, while the effect of each treatment on leaf element content was analyzed by calculating modified z-scores. Generally, the pure chemical fertilizer treatment had a predominantly negative effect on the macro- and microelement uptake of black locust clones (13 significantly negative and five positive relationships), compared to the treatments including organic fertilizer, which showed a predominantly positive effect (12 significantly negative and 27 positive relationships). Among the clones, the element uptake of OBE53 showed the strongest relationship with fertilizer applications.

<https://dx.doi.org/10.17164/EK.2024.08>

Klára CSEKE, Attila BOROVIK, Anikó JAGODICS, Botond Boldizsár LADOS, László NAGY, Attila BENKE and Tamás KOLLÁR:

**The effect of thinning on the genetic structure of beech stands – a genetic and growth assessment of three long-term beech forest thinning trials ...145–163**

**Abstract** – The study aimed to evaluate three long-term beech (*Fagus sylvatica* L.) forest thinning trials from the aspect of changes in forest yield and to explore putative changes in genetic diversity in the stands of Kőszeg, Tormafölde, and Visegrád. In the trials, we analyzed the effect of traditional and intensive thinning on two plots compared to a theoretically unmanaged control plot. Based on the tree yield data sets, we could trace abiotic damages,

and in some cases, unplanned thinnings, especially from the 2000s onwards. The thinning effect on tree yield can adequately be evaluated on the plots of Tormafölde and partly in Kőszeg. The comparative analysis of the genetic diversity of the differently managed plots did not prove that genetic diversity would decrease due to thinning. The plots with the traditional thinning have almost the same or even higher genetic diversity values as the control plot. In the trial in Kőszeg, the two treated plots show higher degree of genetic similarity, while in Tormafölde, the traditionally thinned and the control plots are genetically closer to each other. The plots of Visegrád were not interpretable from both the view of yield changes and genetic patterns. The genetic diversity at the regional level was the highest in the forest stand of Kőszeg and the lowest in Visegrád.

<https://dx.doi.org/10.17164/EK.2024.09>

András SZABÓ, Zoltán GRIBOVSKI, Ján SZOLGAY, Péter KALICZ and Bence BOLLA:

**Investigation of the relationship between groundwater and the root zone in the Püspökladány-Farkassziget study site during the period 2020–2023 ...165–176**

**Abstract** – Forest vegetation is particularly sensitive to rapid environmental changes. In the case of forest stands on the Great Hungarian Plain, such changes may include the decades-long groundwater level decrease and the increasing length of drought periods. We have investigated the relationship between the root system of the forest stand and the groundwater level over four years at our study site at Püspökladány-Farkassziget, which is particularly exposed to aforementioned negative impacts, using high temporal resolution groundwater level and meteorological data. Our results show that by the end of the 2021 growing season, the connection between groundwater and the root system was partially, and by the same period in 2022, it was completely lost. We did not observe any positive changes in 2023. If this situation persists in the long term, it raises questions about the sustainability of the forest stand under investigation.

<https://dx.doi.org/10.17164/EK.2024.10>

Bálint HORVÁTH, Melinda NAGY-KHELL, Máté FARKAS, Tamás Márton NÉMETH, Katalin BEREZKI, Bence BOLLA, Virág JECZÓ, Lászlóné KISS, Valter TOLDI, Tamás FONYÓ and Gábor ILLÉS:

**Study on the stand structure, lying dead trees and site characteristics in the Remetekert forest reserve ...177–193**

**Abstract** – Long-term monitoring system in the Hungarian forest reserves has started in 2005 and almost 40 forests were surveyed up until the present days. The Remetekert forest reserve was investigated in 2022 for the first time; the study focused i.a. on site characteristics (e. g. soil composition) and stand structure, supplemented with the relief model and measurement of lying dead trees. Lessivated brown forest soil dominated in the forest which was suitable for the stand forming forest types: beech woodlands and sessile oak-hornbeam woodlands. Sessile oak was dominant tree species within the site however, beech and hornbeam also were abundant. Average living stock volume was 555.61 m<sup>3</sup>/ha, stand density was 762 stem/ha. Upper and lower canopy layer were typical, characterised by 20 meters and 14 meters average height. The distribution of lying dead trees was unequal, their average quantity was 24.75 m<sup>3</sup>/ha.

<https://dx.doi.org/10.17164/EK.2024.11>

Csaba Béla EÖTVÖS:

**Why we should research canopy processes and what methods are available  
...195–212**

**Abstract** – As a result of climate change, we are experiencing accelerating changes in the canopy, affecting the communities that live there. These communities make up half of the total terrestrial biodiversity. To help maintain the ecological balance, canopy research is important, and researchers began to focus on it in the 1980s, quickly adopting existing tools and developing new ones. Choosing the right one for our purposes can often be difficult from this wide range of tools. This synthetic work is intended to help in these situations while pointing out the methods that can be used to acquire practical knowledge that can be applied in forestry.

<https://dx.doi.org/10.17164/EK.2024.12>





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