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Study of the Influence of Heat Flow on the Time to Ignition of Spruce and Beech Wood

Jozef Harangozó [1], Ivana Tureková [1], Iveta Marková [2,*], Alena Hašková [1] and Roman Králik [3]

1 Faculty of Education, Constantine the Philosopher University, 949 01 Nitra, Slovakia; jharangozo@ukf.sk (J.H.); iturekova@ukf.sk (I.T.); ahaskova@ukf.sk (A.H.)
2 Faculty of Security Engineering, University of Žilina, 010 26 Žilina, Slovakia
3 Department of Russian Language, Peoples' Friedenship University, 117 198 Moscow, Russia; roman.kralik73@gmail.com
* Correspondence: iveta.markova@uniza.sk; Tel.: +421-908-909-938

Abstract: Adherence to fire safety regulations for wood is one of the most important tasks in its use in structural and architectural applications. This article deals with determining the influence of heat flux on the ignition process of spruce (*Picea abies* L. Karst.) and beech wood (*Fagus sylvatica* L.). The heat flux was generated by an electric radiant panel. The analysed parameters included the ignition time of the spruce and beech wood samples, the influence of wood density, and sample moisture, and the course of sample combustion, both with and without flame, was observed. The heat flux was maintained at constant values, depending on the distance of the examined sample from the panel, along with the specific power of the radiation panel. The power of the radiation panel was set to constant values of 5 kW and 10 kW. The samples were placed at distances of 50, 70, 100, 150, and 200 mm from the heat source, and heat fluxes in the range of 13–92 kW·m^{-2} were observed. At a power of 5 kW and a heat flux of 64 kW·m^{-2}, neither the sample of beech nor that of spruce wood, placed at the distance of 100 mm from the radiation panel, exhibited flaming combustion. The ignition time for the beech wood was approximately twice that of the spruce wood, likely due to the higher average wood density. It can be stated that wood density, as one of the main factors, significantly influences the ignition phase of burning. The statistical analysis examined variables including wood type, radiant panel output, distance, and heat flux in relation to ignition time. The analysis revealed a significant difference between ignition time and distance (p-value = 0.0000, H = 37.51583) as well as between ignition time and heat flux (p-value = 0.0000, H = 37.69726). Similarly, the time to ignition for all tested beech wood samples was longer than for spruce wood.

Keywords: beech; spruce; electric radiant panel; temperature of ignition; time to ignition

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1. Introduction

Wood is one of the oldest and most versatile materials used by humans [1,2]. It is used for construction, decoration, and furniture production due to its excellent properties such as a high strength-to-weight ratio and low thermal conductivity. One of its primary drawbacks is its flammability, particularly concerning its extensive use in both residential and non-residential buildings [3–8]. According to the requirements which are laid out in the EN 13501-1, the majority of solid wood and wood products are classified as class D [9–11]. Most wooden elements have a fire reaction class of D-s [12,13].

Wood does not burn directly [14,15]. As a solid combustible substance, wood has a certain fire resistance. The wood initiation process is influenced by the thermal properties of the wood and external conditions [16,17]. Wood combustion is considered to be a two-stage process of pyrolysis and the slow heterogeneous oxidation of carbon [18]. Under the influence of heat flux, wood decomposes into a mixture of volatile substances, tar compounds, and highly reactive carbon residue, initiating processes such as smouldering, ignition, burning, and flame propagation. A charred mass forms on the wood surface [19], while gases mixed with air create a flammable mixture. The presence of flames in the gas phase indicates successful ignition and is internally linked to the heat absorbed by solid materials [20,21]. The flammable mixture can ignite if the fuel–air concentration reaches the appropriate level, along with the required gas temperature. As the surface temperature increases, the charred layer reacts with oxygen from the surrounding environment. The fire continues until the fuel or air supply is exhausted [22,23]. This fact has been confirmed by Thomas et al. [24] and Liu et al. [25]. The initial degradation can be attributed to the loss of moisture content, followed by some degree of dehydration (ca. up to 200 °C), and the main chain pyrolysis of both the amylose and amylopectin fractions, yielding laevoglucose and various other volatile fragments (CO, CO_2, CH_4) [25]. During combustion, cellulose, hemicellulose, and lignin, which are the primary components of wood, undergo dehydration, depolymerization, and thermal decomposition [26–28].

A significant amount of research has been dedicated to identifying the characteristics of the initial stage of a fire to prevent fire disasters and mitigate fire hazards. Numerous experiments and models [29–33] have been developed to study the pyrolysis and combustion behaviour of wood, taking into account various factors such as external sources of energy, materials, and environmental conditions. The significance of experimental studies lies in understanding how materials behave during fires.

Ignition is the ability of a flammable material to ignite under the action of an external thermal initiator and under defined test conditions according to [34,35]. According to ISO 3261 [36], ignition is the ability of a material to ignite. The process of ignition is characterized by the time to ignition of a sample, which depends on the thermal characteristics of materials, the temperature, the sample's conditions (size, humidity, orientation), and the critical heat flux [37]. The ignition temperature can be defined as the minimum temperature to which the air must be heated so that the sample put in the heated air environment ignites. The authors of [38–40] defined the ignition temperature as the surface temperature of the sample just before the ignition point.

The aims of this article are the following:

- To verify the dependence of the heat flow on the wood density and flammability of materials based on the prediction of the physical properties and fire characteristics of spruce (*Picea abies* L. Karst.) and beech (*Fagus sylvatica* L.) wood samples;
- To experimentally determine the time to ignition (TTI) of spruce and beech samples;
- To investigate the significant impact of heat flux (in the range of 13–92 kW.m^{-2}) generated by an electric radiant panel (at two power levels of 5 kW and 10 kW) and the position of samples (at the distance of 50, 70, 100, 150, and 200 mm from the heat source) on the ignition temperature and time to ignition.

2. Materials and Methods

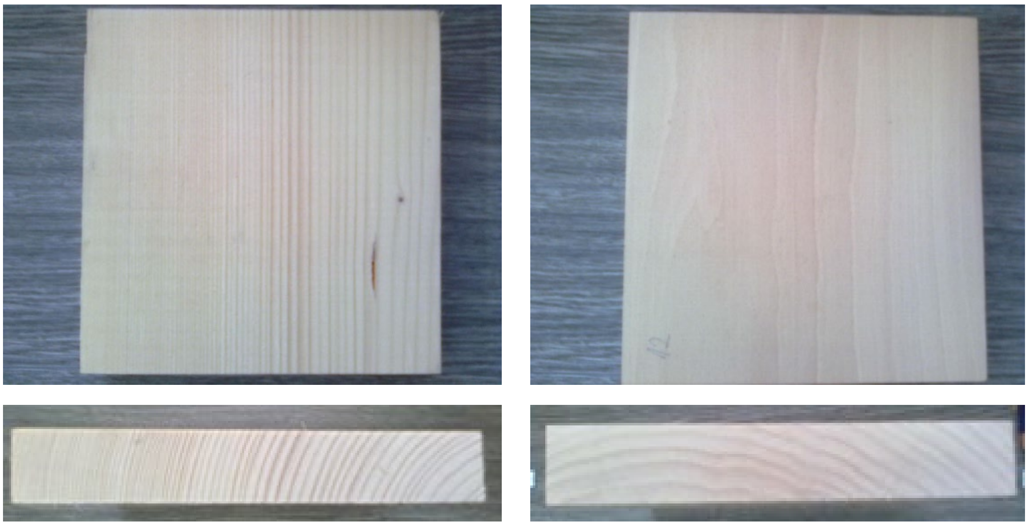
2.1. Materials

For the experimental verification, samples of spruce wood (*Picea abies* L.) and beech wood (*Fagus sylvatica* L.) were selected. These types of wood are among those that are commonly used in Slovakia's industrial sector [41], with beech representing hardwood and spruce representing softwood.

Beech wood (*Picea abies* L.) exhibits relatively high bending strength, impact toughness, and compressive strength. Due to its neutral appearance in its natural state, it can be easily colour treated on the surface. Among the advantages of its processing are its excellent ability to absorb impregnating coatings and stains, good density, hardness, and strength, flexibility that is ideal for bending, and affordability.

Spruce wood (*Fagus sylvatica* L.) is yellowish to yellow-brown, shiny, and has no heartwood colouring, making it generally very lightweight. Due to its prevalence as the second most common species in Slovak forests and its favourable physical and mechanical properties, spruce wood is an exceptionally important raw material for our industry.

The wood samples were cut crosswise through the growth rings using a band saw. The prepared samples had a square shape with a side length of 165 mm and a thickness of 25 mm (Figure 1a,b).



(**a**) (**b**)

Figure 1. (**a**) Test sample of spruce wood; (**b**) test sample of beech wood.

Surface treatment of the boards was performed by planing (with a combined woodworking machine Woodster C6 06, Woodster GmbH, Ichenhausen, Germany). Surface roughness is one of the factors influencing the ignition of samples [42]. The average density of the tested spruce wood samples was 422.9 kg·m^{-3} and beech wood was 697.2 kg·m^{-3}. The determination was carried out in accordance with the standard STN EN 323:1996 [43]. The measured wood density results correspond to the wood density reported by the authors Požgaj et al. [44] and Konofalska et al. [45]. The variation in densities among individual wood samples depends on factors such as moisture content, position within the tree, tree age, and growth rate [46–48] (Table 1).

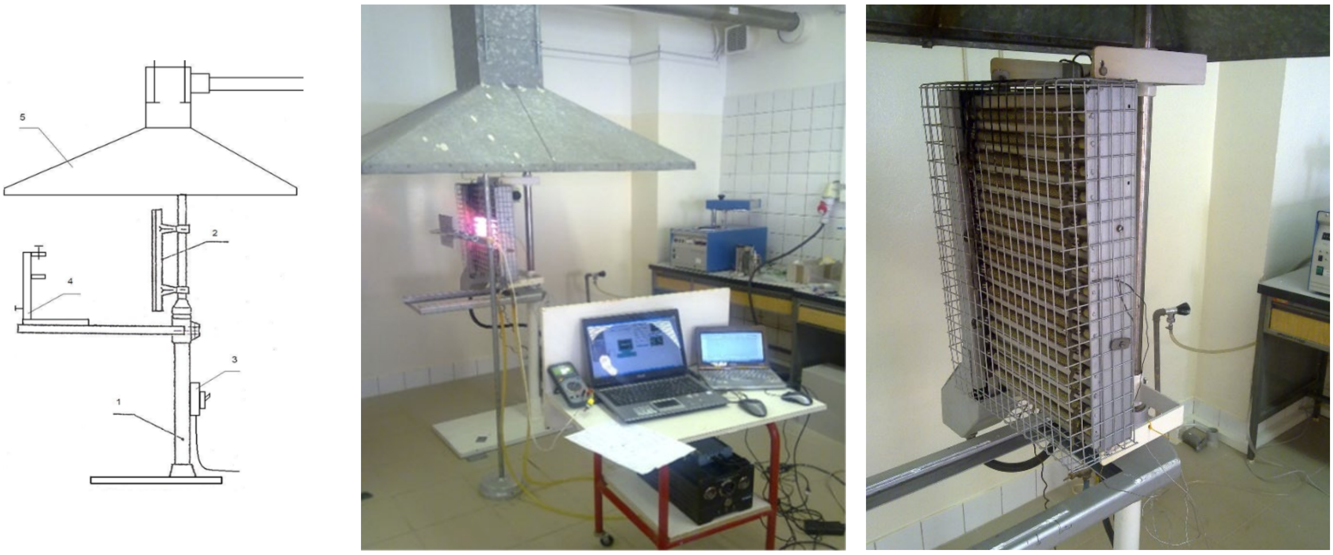
Table 1. Physical parameters of samples.

Parameters	Beech *Fagus sylvatica* L.	Spruce *Picea abies* L. KARST.
Density (kg·m^{-3})	697.2	422.9
Moisture (%)	6.4 ± 0.5	6.3 ± 0.5

Wood is a hygroscopic material in relation to the surrounding environment, capable of absorbing or releasing water in both liquid and gaseous states and changing its moisture content according to the humidity of the surrounding environment [49,50]. Determination of the moisture content of the wood was carried out in accordance with the standard EN 322:1996 [51]. Spruce wood (*Picea excelsa* L.) had an average moisture content of 6.4 ± 0.5%, while beech wood (*Fagus silvatica* L.) had a moisture content of 6.3 ± 0.5%. Moisture content influences the time to ignition; as moisture content increases, more heat is required for the initial drying process and subsequent thermal degradation [52]. Moisture content corresponded to the moisture in the environment and was very similar between these samples.

2.2. Methods

The experimental device was designed and labelled as an "electric radiant panel". The electric radiant panel (Figure 2a–c) was constructed for experimental tests aimed at determining the ignition of the material depending on the magnitude of the heat flux. The design process was preceded by a study of published research papers [53–55] that dealt with similar devices. The electric radiant panel was powered by the 400 V electrical network, and the panel's power was controlled using three protective fuses.



(a) (b) (c)

Figure 2. Electric radiant panel. (**a**) Diagram of the electric radiant panel with description of individual parts: 1. stand; 2. radiant panel; 3. electrical fuses; 4. frame for sample attachment; 5. exhaust hood; (**b**) example of the electric radiant panel during measurement; (**c**) detail on the electric radiant panel.

Each of the three fuses controlled one phase with five electric coils. Fifteen coils were used to adjust the panel power to 5 kW, 10 kW, or 15 kW. The constructed device is depicted in Figure 2 as a schematic, and Figure 2b,c shows the real representation.

For the pre-experimental measurement, a water-cooled heat flux sensor SCHMIDT—BOELTER SBG01—100 (Hukseflux Thermal Sensors B.V., Delft, The Netherlands) was used (Figure 3). The SBG01 sensor used is designed for measuring flame heat flux in the range of high heat flux levels of up to 200 kW·m^{-2}.

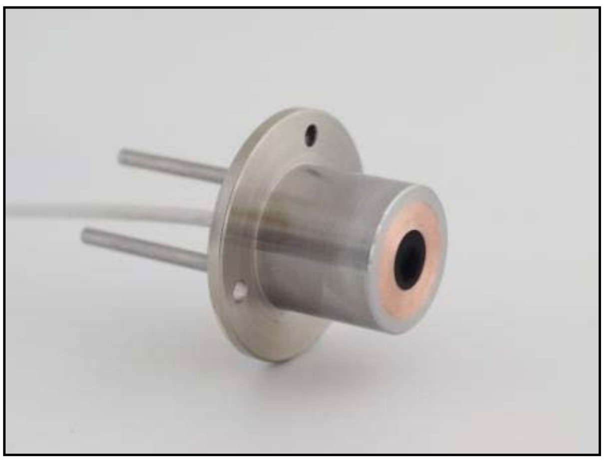


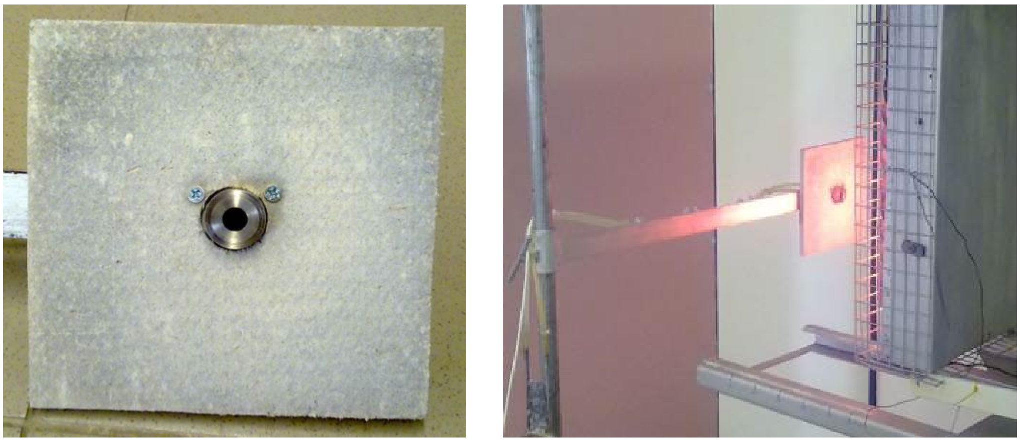
Figure 3. Water-cooled heat flux sensor SCHMIDT-BOELTER SBG01-100 [44].

The SBG01 passively generates an output voltage proportional to the incoming heat flux using a thermoelectric sensor. Assuming the heat flux is constant, the thermal conductivity of the device is constant, and the sensor has a negligible effect on the heat flow, the SBG01 signal is proportional to the local heat flux ($W \cdot m^{-2}$). Calibration of the sensor is required before measurement. Measurement accuracy depends on sensor properties, calibration quality, and measurement errors [56]. The sensor was calibrated against a reference sensor at NIST [57,58].

The total uncertainty, according to ISO 14934-4:2014 [59], is estimated to be within ±3%, relative to the standard uncertainty multiplied by the coefficient k = 2, providing a reliability level of 95%.

To capture and monitor the temperature of the radiant panel, two thermocouples (Ni-Cr-Ni) were used, which were positioned directly on the panel, with their ends connected to a high-performance, multifunctional data acquisition module OMB-DAQ-2416 (Multifunctional Data Acquisition Module OMEGA OMB-DAQ-2416, Omega Engineering, Norwalk, CT, USA). This module was further connected to a computer, where data obtained from the analogue inputs of the thermocouples were stored and displayed using Tracer DAQ-2416 software (Omega Engineering, Norwalk, CT, USA).

The accuracy of the measured values during the determination of the heat flux was ensured by using a calibration plate with dimensions identical to those of the tested samples (165 × 165 × 25) mm (Figure 1). In the centre of the calibration plate, a radiometer was inserted, which was mounted on a stand with the ability to adjust the desired distances (50, 70, 100, 150, and 200 mm) from the radiant panel (Figure 4).



(**a**) (**b**)

Figure 4. (**a**) Diagram of the calibration plate with a radiometer for determining the heat flux values at specific distances; (**b**) determination of heat flux.

The heat flux sensor was connected to the multimeter METEX M-4640A (B&B Electronics Mfg. Co., Inc., Ottawa, IL, USA), which generated an output voltage proportional to the heat flux. The multimeter was interfaced with the DMM MULTIVIEW programme (B&B Electronics Mfg. Co., Inc., Ottawa, IL, USA). The original results were recorded as output voltage values in mV and subsequently converted to heat flux units in $kW \cdot m^{-2}$ (Figure 5).

The test was conducted in a laboratory environment without airflow. The results confirmed the general validity of the idea that as the distance from the radiant heat source increases, the density of the measured heat flux decreases.

The experiments, including calibration, were repeated three times with the samples to ensure the reproducibility of the measured values.

For each power level of the radiant panel, distances were determined in such a way as to enable the observation of sample's flame combustion.

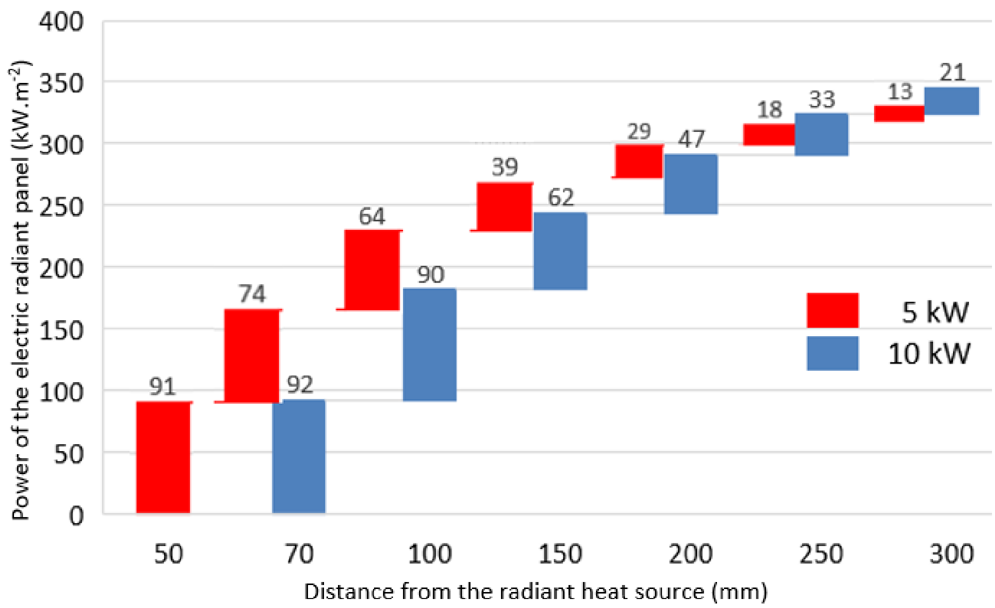


Figure 5. Measured heat flux values depending on the power of the electric radiant panel and the distance from the radiant heat source. Red colour represents 5 kW power, and blue represents 10 kW.

2.3. Method and Evaluating the Obtained Results

The aims of the experimental measurement were the following:

- To determine the time to ignition of samples of beech and spruce wood exposed to the selected value of radiant heat flux. The measurement of the time to ignition of the sample (HAMA Sports Stopwatch SW-104, HAMA GmbH & CoKG, Monheim, Germany) represented the interval from the time the sample was placed in the holder at the specific distance until permanent surface ignition of the sample occurred. If permanent surface ignition did not occur and the sample only burned without flames, the test was terminated after 15 min.
- To evaluate the results using the statistical method ANOVA according to the STATISTICA 10 programme.

Visual assessment of the samples' behaviour, such as decomposition by smouldering, foaming, crumbling, cracking, stretching, or shrinking of the exposed surface of the sample, was also part of the test.

3. Results and Discussion

The results of the time to ignition measurements for the spruce and beech wood samples are presented in Table 2, and the average time to ignition values (TTI) depending on the distance from the heat source are shown in Figure 6. This figure provides the time to ignition values of spruce wood samples at a radiant panel power of 5 kW and sample placements at the distance of 50, 70, and 100 mm from the electric radiant panel.

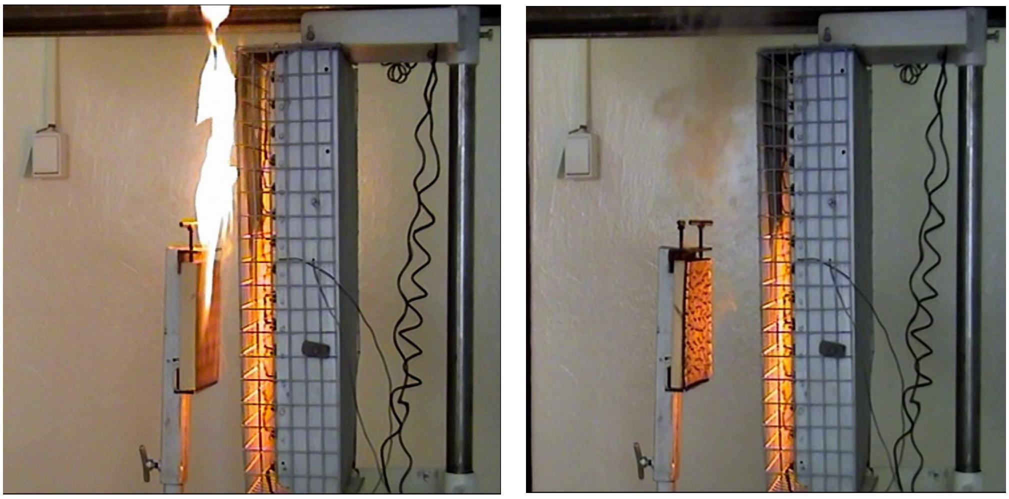
At a radiant power of 5 W, both the spruce and beech wood exhibited flaming combustion for all of the heat flux values, except for the last sample of beech wood which was placed at the distance of 100 mm, corresponding to a heat flux value of 64 kW·m^{-2}. Non-flaming combustion was observed for 15 min. Examples of flaming (Figure 6a) and non-flaming (Figure 6b) combustion of beech wood at radiant power of 5 W are shown in Figure 6.

For the spruce wood with a radiant panel power of 10 kW, flaming combustion of the sample occurred at distances of 100 mm and 150 mm (corresponding to heat fluxes of 90 and 62 kW·m^{-2}). At a distance of 200 mm from the radiant heat source (heat flux of 47 kW·m^{-2}), flaming combustion of the sample did not occur, but the effect of the heat flux manifested as non-flaming combustion.

Table 2. Time-to ignition of spruce and beech wood samples depending on the radiant power, density, and sample distance.

Radiant Power (kW)	Distance from the Heat Source (mm)	Radiant Heat Flux (kW·m^{-2})	Spruce			Beech		
			Density (kg·m^{-3})	Time-to-Ignition (s)	Flame (+/−)	Density (kg·m^{-3})	Time-to-Ignition (s)	Flame (+/−)
5	50	91	420.38 ± 50.96	9 ± 1.54	+	701.41 ± 30.67	22.4 ± 7.49	+
	70	74	412.63 ± 54.34	15.2 ± 2.92	+	695.87 ± 21.23	30.2 ± 4.16	+
	100	64	421.7 ± 30.46	38.4 ± 3.26	+	688.83 ± 17.68	X	−
10	100	90	420.05 ± 52,18	16.2 ± 1.6	+	698.74 ± 16.82	23.6 ± 1.62	+
	150	62	420.50 ± 52.74	82.6 ± 10.57	+	697.536 ± 26.76	82.2 ± 10.57	+
	200	47	421.7 ± 30.46	X	−	700.72 ± 21.9	X	−

Note: + flaming combustion; − non-flaming combustion; X—there were no initiations.



(**a**) (**b**)

Figure 6. Examples of flaming and non-flaming combustion of beech wood samples exposed to various heat fluxes. (**a**) Sample of beech wood, heat flux of 91 kW·m^{-2}, distance of 50 mm in 10 s; (**b**) sample of beech wood, heat flux of 64 kW·m^{-2}, distance of 100 mm in 140 s.

Similar behaviour was also observed with the beech wood samples, where at a heat flux of 47 kW·m^{-2}, non-flaming combustion occurred.

We observe an increase in time values with increasing distance when comparing the obtained values of tSP for individual heat fluxes (Figure 6). Interestingly, different tSP values were observed when the radiant panel power was evaluated using a distance of 100 mm for both the 5 and 10 W powers (Table 1).

On the contrary, at the distance of 150 mm and a radiant panel power of 10 kW, there was an equal time to ignition (Figure 6) for both the beech and spruce samples.

Thanks to the abundance of the obtained experimental outputs, it was possible to utilize the statistical method ANOVA to monitor the significant influence of selected factors (wood species, radiant panel power, distance from the heat source) on the experimentally determined time to ignition (Table 3).

Table 3. Kruskal–Wallis test for the following variables: wood species, radiant panel power, distance, and heat flux, depending on the ignition time.

Time-to-Ignition	Wood Species	Radiant Panel Power	Distance	Heat Flux
p-value	0.8115	0.6494	**0.0000**	**0.0000**
H	0.0568664	0.2066405	**37.51583**	**37.69726**

The evaluation of the obtained values was verified using a mean and standard deviation dot plot for each group of results (Figure 7). The heterogeneity of the variance was demonstrated, which was confirmed by the Levene's test for the homogeneity of variance that was performed, with results of p-value = 0.0000 and F = 8.110353.

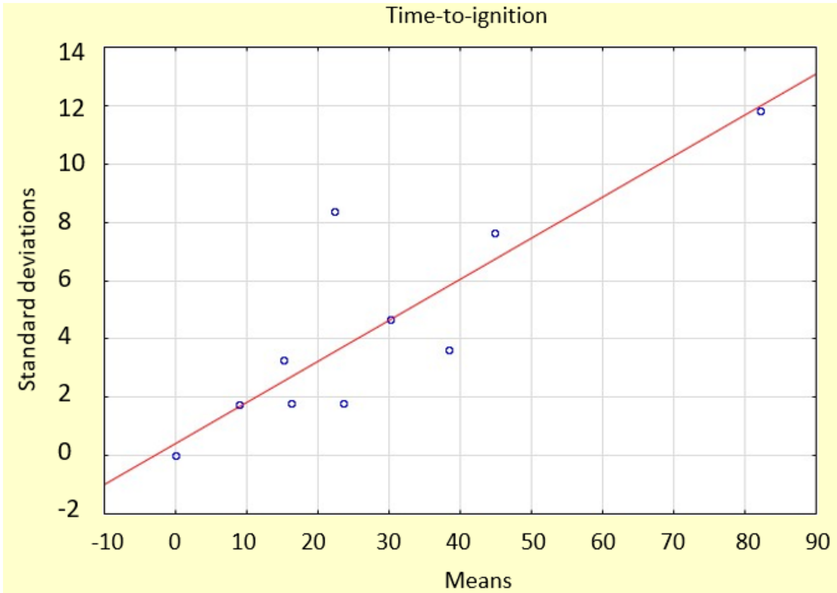


Figure 7. Dot plot: means and standard deviations, where each point on the graph represents 1 group of results.

Subsequently, the Kruskal–Wallis test was conducted for the following variables: wood species, radiant panel power, distance, and heat flux, depending on the ignition time (Table 3 and Figure 8).

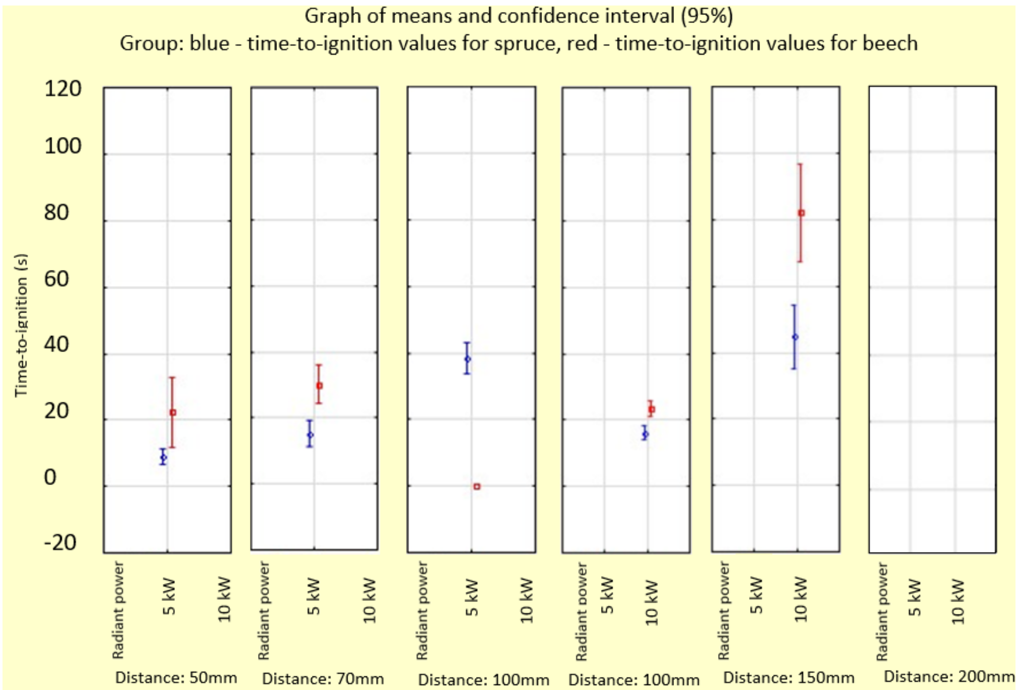


Figure 8. Box plots—Multifactor Analysis of Variance (ANOVA) (95% confidence). Legend: Blue symbols represent time to ignition values for spruce, red symbols represent time to ignition values for beech.

Based on the given data, it could already be proven that there was a difference between the time to ignition and distance (p-value = 0.0000, H = 37.51583) and time to ignition and heat flux (p-value = 0.0000, H = 37.69726). Multiple comparisons were then made between these variables (see Tables 4 and 5).

Table 4. Multiple comparisons of p-values (two-sided); time to ignition (descriptive statistics table) Independent (grouping) variable: heat flux; Kruskal–Wallis test: H (5, N = 60) = 37.69726 p = 0.0000.

	47—R:8.0000	**62—R:54.750**	**64—R:28.500**	**74—R:33.900**	**90—R:31.800**	**91—R:26.050**
47		0.000000	0.130067	0.013690	0.034639	0.312438
62	0.000000		0.011650	0.113923	0.049479	0.003573
64	0.130067	0.011650		1.000000	1.000000	1.000000
74	0.013690	0.113923	1.000000		1.000000	1.000000
90	0.034639	0.049479	1.000000	1.000000		1.000000
91	0.312438	0.003573	1.000000	1.000000	1.000000	

Table 5. Multiple comparisons of p-values (two-sided); time to ignition (descriptive statistics table) Independent (grouping) variable: distance; Kruskal–Wallis test: H (4, N = 60) = 37.51583 p = 0.0000.

	50—R:26.050	**70—R:33.900**	**100—R:30.150**	**150—R:54.750**
50		1.000000	1.000000	0.002382
70	1.000000		1.000000	0.075949
100	1.000000	1.000000		0.002759
150	0.002382	0.075949	0.002759	

Interpretation of the results can be based on the developed box plots (Figure 8). Figure 8 illustrates the nature of the obtained results. The first three columns represent the time to ignition values for a radiant panel power of 50 kW (labelled as 5) based on the distance of the sample from the panel. The remaining three columns present the results for a radiant panel power of 100 kW. In both cases, the trend of increasing ignition time with increasing distance from the source and decreasing heat flux intensity was confirmed. For samples of spruce at a power of 50 kW, a linear increase in time to ignition was observed (Figure 9). However, for beech samples, this dependence was observed, as ignition did not occur during the 10 min period at a distance of 200 mm.

In both cases, the beech samples consistently exhibited higher time to ignition values. The red dot in the third column in Figure 8 represents a zero value, indicating that the beech samples at the distance of 100 mm with a heat flux of 64 kW·m^{-2} and a radiant panel power of 50 kW did not ignite (also indicated in Table 1).

As observed from the obtained boxplots, the results exhibit a relatively wide dispersion (Figure 8 and Table 1). This phenomenon arises from the heterogeneity of the wood samples. This observation is further supported by the results obtained from measuring the density of the samples (shown in Table 1).

The results for the time-to-ignition (TTI) of beech and spruce at a power of 100 kW, with heat fluxes of 92 and 62 kW·m^{-2} and distances of 100 and 150 mm (Figure 9), remain consistent. The TTI for beech is higher, but the differences are not high enough to establish a significant dependence, as indicated by the statistical analysis in Table 2. At the distance of 200 mm, flaming combustion did not occur within the 10 min time frame (Figures 10 and 11).

An example of visual changes in spruce wood due to the effect of radiant heat at 5 kW power is shown in Figure 10, and that at 10 kW power is shown in Figure 11.

Mindykowski [60] used the time to ignition for a piece of wet spruce and compared it to the time to ignition of dry wood to create a model. One of the reasons for their results is that the ignition temperature in the experiments (directly linked to the intercept heat flux) was constant for both the dry and the moist wood [13,55,61–64].

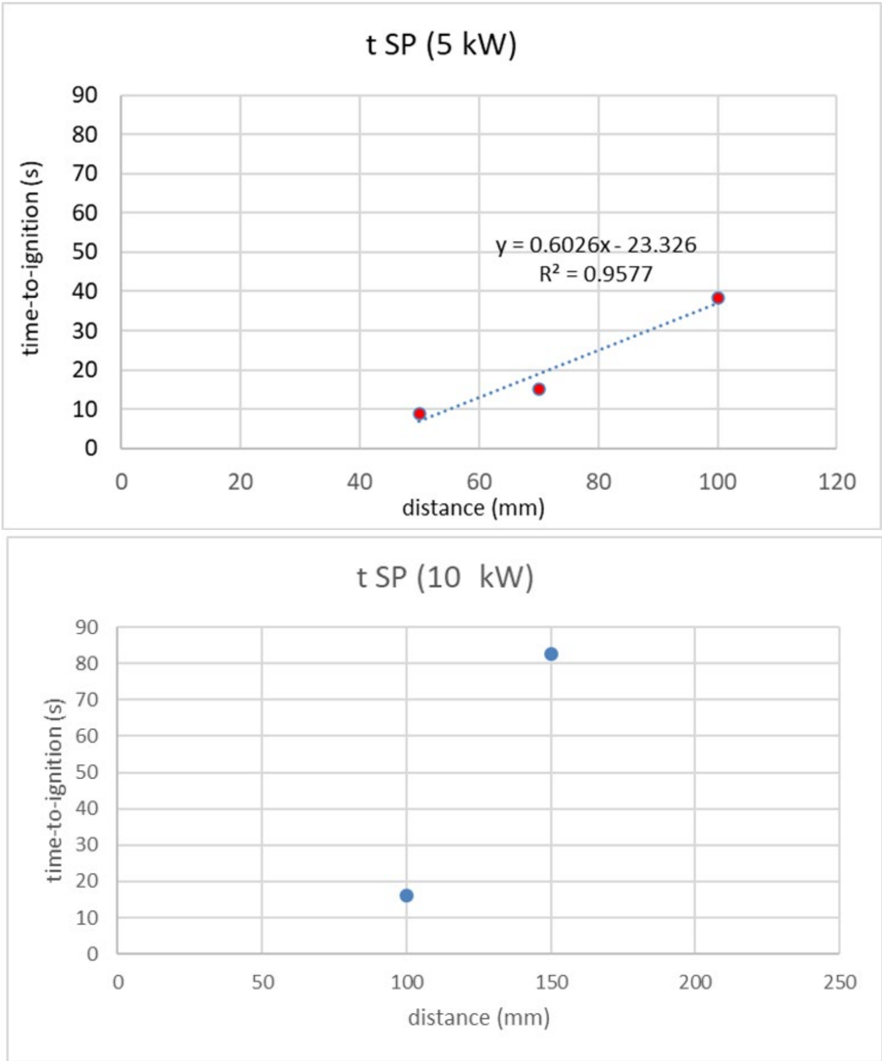
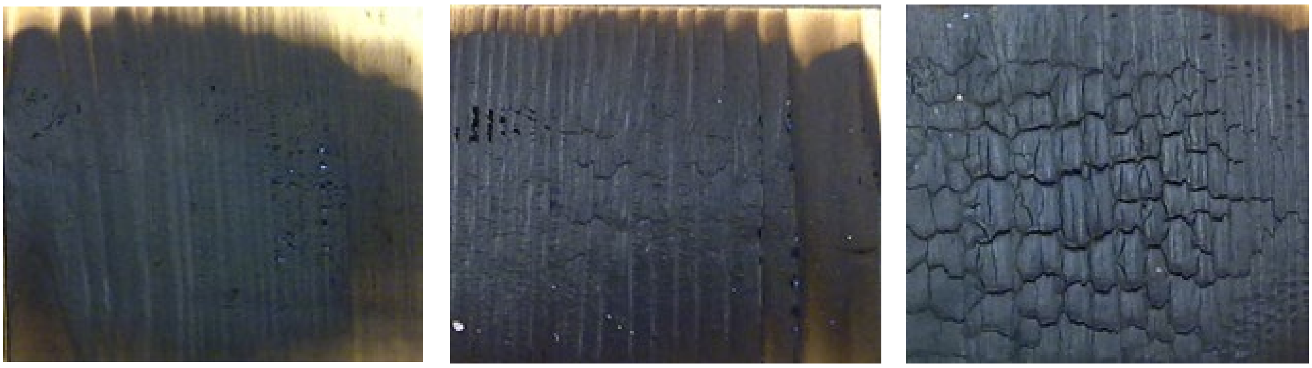


Figure 9. Example of the dependence of time to ignition on the distance of the sample from the heat source for spruce samples.



(**a**) (**b**) (**c**)

Figure 10. Visual observations of the influence of different heat fluxes on samples of spruce wood after burning at a radiant panel power of 5 kW. Legend: (**a**) image at 9 s with a heat flux of 91 kW·m^{-2}, subsequently extinguished; (**b**) image of the burned sample exposed to a heat flux of 74 kW·m^{-2}, burning with flames; (**c**) image represents the residue after flaming combustion under a heat flux of 64 kW·m^{-2} for 10 min.

(**a**) (**b**) (**c**)

Figure 11. Visual observations of the influence of different heat fluxes on residues of spruce wood samples after burning at a radiant panel power of 10 kW. (**a**) Thermally stressed sample of spruce wood with a heat flux of 90 kW·m^{-2} at 17 s; (**b**) sample exposed to a heat flux of 62 kW·m^{-2}, burning with flames; (**c**) residue after non-flaming combustion under a heat flux of 47 kW·m^{-2} for 10 min.

Spruce is a very interesting wood material. Other researchers evaluated the behaviour spruce during and after various thermal loading [13,61–63].

For example, Zachar et al. [55] assessed the influence of a higher heat flux on spruce wood's (*Picea abies* L.) behaviour. The heat fluxes of 15, 20, 25, and 30 kW·m^{-2} were used. They determined the fire-technical properties of the wood, such as the mass burning rate, charring thickness, and charring rate, as well as the chemical composition (contents of the extractives, lignin, cellulose, holocellulose).

The same procedure for evaluating the experiment was followed for the beech wood samples as well. Images of the samples exposed to a 5 kW radiant panel heat are presented in Figure 12, and those exposed to a 10 kW radiant panel heat are shown in Figure 13.

(**a**) (**b**) (**c**)

Figure 12. Visual observations of the influence of different heat fluxes on residues of beech wood samples after burning at a radiant panel power of 5 kW. (**a**) Thermally stressed beech sample with a heat flux of 91 kW·m^{-2}, but immediately after its ignition, the flame was extinguished to document the initial phase of flaming combustion; (**b**) beech sample exposed to a heat flux of 74 kW·m^{-2}; (**c**) Heat flux of 64 kW·m^{-2} to which the sample was thermally exposed for 10 min. This is the residue after flaming combustion.

(**a**) (**b**) (**c**)

Figure 13. Visual observations of the effects different heat fluxes on residues of beech wood samples after burning at a radiant panel power of 10 kW. (**a**) Thermally stressed beech sample with a heat flux of 91 kW·m^{-2} (after 16.2 s); (**b**) wood exposed to a heat flux of 62 kW·m^{-2} and (**c**) burning with flames.

Preimesberger et al. [63] focused their attention on the influence of size and temperature of the heating on the auto-ignition of beech (fagus sylvatica) and spruce (picea abies) wood cubes. The experiments were conducted in a furnace at five isothermal temperatures (240 °C, 270 °C, 300 °C, 330 °C, and 360 °C) with four cube sizes (5 mm, 10 mm, 15 mm, and 20 mm). The point of pyrolysis was identified at 360 °C. After pyrolysis, a combination of internal heating and heterogenous oxidation reactions on the surface lead to ignition and combustion.

Kytka et al. [64] carried out an experiment involving three distinct wood species, namely spruce, alder, and beech, which were combined in various arrangements. Various parameters were measured during combustion, namely time to ignition (TTI), mass loss rate (MLR), the heat release rate (HRR), the peak heat release rate (pHRR), the peak average rate of heat emission (MARHE), the effective heat of combustion (EHC), and the average rate of heat emission (ARHE) [50]. The time to ignition (TTI) was consistent, occurring between the first and second minute across all tested wood species and combinations. This result was similar to that in our research, but this study used the cone calorimeter method.

The results of the experiments indicate that as the heat flux decreases, the ignition time of the individual samples burning with flames increases. This fact can be explained by the gradual heating of the sample exposed to a constant heat flux. The temperature rises, leading to the release of volatile substances. If the exposure to heat flux continues, the temperature may reach a critical value, or the gas concentration may be high enough to cause ignition. It is evident that the higher the heat flux, the sooner ignition occurs. Despite identical conditions and exposure to heat flux, we have found that the type of wood, characterized by different densities, significantly influences the material's behaviour during the ignition phase and, consequently, it also affects its contribution to fire development.

4. Conclusions

The primary objective of the experimental measurement was to observe the flammability of samples using radiant heat flux, independent of any other ignition source.

The conclusions from the experiment can be summarized as follows:

- With a radiant panel power of 5W, flaming combustion occurred for samples of spruce and beech wood at all distances (50, 70, and 100 mm), for all heat flux values, except for the last sample of beech wood placed at a distance of 100 mm, corresponding to a heat flux value of 64 kW·m^{-2}.

- In the experimental results, the ignition time for beech wood was approximately twice that of spruce wood, likely due to the higher average wood density (700.72 ± 21.9 kg·m^{-3} for beech wood compared to 421.7 ± 30.46 kg·m^{-3} for spruce wood).
- With a radiant panel power of 10 W, flaming combustion was observed for samples of spruce and beech wood only at two distances (100 and 150 mm). At a distance of 200 mm (with a corresponding heat flux of 47 kW·m^{-2}), the samples did not undergo flaming combustion; however, the influence of heat flux was evidenced by non-flaming combustion.
- The statistical analysis, employing ANOVA followed by the Kruskal–Wallis test, examined variables including wood type, radiant panel output, distance, and heat flux in relation to ignition time. The analysis revealed a significant difference between ignition time and distance (p-value = 0.0000, H = 37.51583) as well as between ignition time and heat flux (p-value = 0.0000, H = 37.69726).
- Time-to-ignition values significantly depend on both the radiant panel output and the distance of the sample from the heat source.
- As the radiant panel power increased, the differences in the time to among the tested samples also increased.

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