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The Effect of Microbial Degradation on the Gasoline Residues Identification in Fire Debris

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Short report

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Abstract

The identification of ignitable liquid residues in fire debris is a key finding for determining the cause of the fire and indicate that it was intentional fire. However, ignitable liquids in the samples are subject to evaporation as well as microbial degradation. The aim of this work is to investigate accelerators and their changes due to microbial degradation in fire debris. Gasoline changes in different soil types and different time intervals were compared. Based on several authors, mainly alkanes decompose and thus change the chromatogram, from which ignitable liquids are subsequently incorrectly identified. The results indicate the need for rapid and timely analysis of fire debris in laboratories or their storage under specified conditions, therefore freezing to the specified temperature.

Keywords: Gas chromatography – mass spectrometry, gasoline, ignitable liquids, microbial degradation, soil

1 Introduction

Detection of ignitable liquids is crucial in determining cases of arson. In many cases, an arson uses an ignitable liquid to accelerate a fire. Most ignitable liquids are hydrocarbon-based fuels. Gasoline is the most used ignitable liquid because it is easily accessible, inexpensive, and easily ignited. Gasoline and other ignitable liquids are classified according to the American Society for Testing and Materials (ASTM) guidelines according to their boiling point range and chemical composition. Other common consumer products, which are classified according to chemical composition and boiling point, may also be used. Other product classes include petroleum distillates (e.g., diesel), isoparaffins (e.g., paint thinner), aromatics (e.g., degreasers), naphthenic paraffinic substances (e.g., lamp oil), n-alkanes (e.g., candle oil), de-aromatized distillates (e.g., camping fuel), oxidized solvents (e.g., ketones) and various products such as turpentine. Identification of ignitable liquids is a challenging task that can be affected by several factors. Microbial degradation is one of the three main processes that can change the composition of ignitable liquid residues. Because biodegradation is a time-related aspect, it should be studied at different stages of its development. Although the debate on microbial degradation is relatively new to investigators of the causes of fires, it has long been of interest to environmental researchers and the oil industry. As early as 1946, Claude ZoBell documented that hydrocarbon could be used by microorganisms as their only source of energy (Atlas, 1981; Hybská et al., 2018, Stauffer et al., 2008; ASTM E1618-19; ASTM E1618-06).

The role of the investigator of the causes of the fire in these cases is twofold: to remove the remnants of ignitable liquid from the matrix and to determine the type of ignitable liquid present. While the analysis of volatile compounds in solid matrices is an active area of research, forensic scientists have adopted only a few selected methods for the analysis of fire samples. The use of standardized methods ensures consistency between laboratories and confidence in the results after they are brought to court. Methods for which American Society for Testing and Materials (ASTM) standards have been established include steam distillation, solvent extraction, headspace sampling, passive and dynamic headspace method, and solid phase microextraction (SPME) (Turner, Goodpaster, 2009).

Each of these methods has its strengths and weaknesses. For example, steam distillation is useful only if there is a large amount of ignitable liquid in the sample. Solvent extraction is also an approved ASTM method and is a useful method when the samples are very small, when the ignitable liquid contains compounds with very high boiling points, or when the matrix is unsuitable for extraction of the ignitable liquid by other methods. However, steam distillation and solvent extraction are time and labour intensive compared to their efficiency, and key compounds may be lost in the process where background interference may occur. Modern extraction methods use dynamic and passive headspace methods. These methods allow ignitable liquids to escape and concentrate on the adsorption medium, which can then be desorbed for analysis. The dynamic headspace method involves the use of an inert gas to continuously clean the headspace of the sample, allowing complete extraction of the ignitable liquid from the matrix. Thermal desorption is then used to release the ignitable liquid from the sorption material. The dynamic headspace method is not as often used as passive due to the work involved and can thus allow contamination of the ignitable liquid (Dolan, 2003; Sandercock, 2008).

The method used in forensic laboratories is primarily a passive headspace method. Its advantage is a much simpler method for sample extraction and is also non-destructive, which makes it the preferred method for sample extraction. As with the dynamic method, the ignitable liquid is evaporated and collected on an adsorbent material, usually a porous polymer or carbon. The ignitable liquid can then be thermally desorbed from the strip or extracted with a solvent. The difference between the passive and dynamic methods is that for the passive, the inert gas is not used to expel the ignitable liquid from the headspace to the adsorbent material. Instead, the adsorbent material is suspended in the headspace, during heating of the sample. This method also uses a closed system, while the dynamic method does not. Another advantage of the passive method is that it allows the sample to be stored for re-analysis if necessary. Suitable solvents for the passive method should be able to displace the compounds in the ignitable liquid from the adsorbent material and should have a high solubility for these compounds. Typical solvents include carbon disulfide or pentane. Solid phase microextraction (SPME) is a relatively new technique for analyzing fire samples that uses silica fiber instead of a carbon strip. The fiber is enclosed in a hypodermic syringe so that the fiber can be exposed to the sample and then withdrawn for analysis. SPME is a versatile method that can be used in the headspace method, the direct method, or the partial headspace method (Turner, Goodpaster, 2009).

Regardless of the extraction method, the method of identifying samples of ignitable liquids in laboratories is universal gas chromatography, usually using silicone columns and either by flame ionization or mass spectrometry. In contrast, the aspect by which microorganisms metabolize oil components is not as well known among forensic scientists, although it has been well studied over the last few decades. For example, the original microbial communities found in oil fields are very diverse and include many species of bacteria. Numerous trends and observations that have been reported in the literature regarding the degradation of certain classes of hydrocarbons in oil can be summarized as follows (Hybská et al., 2018, Magot, 2005; Turner, Goodpaster, 2009):

- C_6 to C_{15} n-alkanes are the most easily degradable components of petroleum.
- A typical first sign of biodegradation is the loss of n-alkanes ranging from C_{10} to C_{13}.
- Aromatic hydrocarbons are more resistant to degradation than aliphatic hydrocarbons.
- Cyclic and branched alkanes are more resistant than direct hydrocarbons.
- Resistance to degradation increases with the degree of substitution in isoalkanes, alkylcyclohexanes, alkylcyclopentanes and alkylbenzenes.
- Resistance to degradation also depends on substitution effects (e.g., 3-methylalkanes> 4-methylalkanes> 2-methylalkanes).

- Adjacent methyl groups (e.g., 1,1-dimethylcyclohexane and 1,2,3-trimethylbenzene) also increase resistance to biodegradation.
- Degradation in heavier aliphatic hydrocarbons tends to occur in the order in which n-alkanes are removed first and then acyclic isoprenoid alkanes.

The aim of the paper is to point out the microbial degradation of ignitable liquids in the soil. Whereas ignitable liquids in fire samples may, due to microbial degradation, change their formula, according to which they can be distinguished and determined in ion chromatograms. In microbial degradation, the diagnostic formulas used to identify ignitable liquids change more unpredictably than in weathering. Instead of gradually losing entire groups based on volatility, losses are limited to individual compounds in the groups based on the preferences of the microbes present in each sample.

2 Material and Methods

The data and results of two studies of microbial degradation of gasoline in different soil types and at different time intervals were compared. Based on their research and results, the decomposition of ignitable liquids due to microbial degradation was evaluated.

Bacteria tend to consume petroleum products, and this has an adverse effect on the identification of ignitable liquids, especially in highly organic samples such as soils. D.C. Mann and W. R. Gresham (1990) from a laboratory in Washington first examined this phenomenon in the context of the analysis of fire samples. Using gasoline-enriched garden soil, this study showed that degradation occurred rapidly unless the soil was either thoroughly sterilized prior to the introduction of gasoline or gasoline or soil samples were stored at -5 °C. For unsterilized samples stored at room temperature, the degradation process was characterized by the loss of substituted benzenes and all n-paraffin compounds over several days. However, the isoparaffinic compounds were not affected. Based on these findings, the authors stated that all soil to be transferred to the laboratory will henceforth be stored in a freezer until analysis is complete (Dann, Gresham, 1990; Turner, Goodpaster, 2009).

Dinan et al., (1992) isolated two species of bacteria (Pseudomonas putida and Pseudomonas fluorescens biovar III) from soil samples that generated an anomalous chromatographic pattern. The ability of these bacteria to degrade gasoline and petroleum gasoline was evaluated in vitro and the two species were found to complement each other because Pseudomonas putida consumed the aromatic parts of the fuels, while Pseudomonas fluorescens biovar III the aliphatic part. Finally, the authors offered recommendations to prevent microbial degradation, such as storing samples at reduced temperature or adding a non-volatile bactericidal agent to fire residues (Mann, Gresham, 1990; Dinan et al., 1992).

In an article by Turner et al. (2014) focused on microbial changes of ignitable liquids in soil obtained from an agricultural field and was clay, the second was taken from the yard and it was sandy Miami clay, and the last sample was ordinary urban soil from the brownfield area, and it was Wawaka clay. All material was collected from the surface to a depth of 20 cm using a sampling probe, which was then sieved. Bacterial populations were determined for each soil type. For each soil sample, 20 µl of standard unleaded petrol (87 octane) per 100 g of soil was added three times in a clean, unused container. Samples were sealed and stored for 0, 2, 4, 7, 11, 15, 22 and 30 days. On designated days, samples were extracted by the passive headspace method. The activated carbon strip, which hung with a clip on the nylon fiber, was placed in a can in the headspace. The sealed cans were heated at 85 °C for 4 hours. After cooling, the strips were removed and extracted with 400 µl of pentane for approximately 1 minute. Samples were then analysed by GC-MS (Agilent 6890 GC with Agilent 5975 MSD) using a standard method for the analysis of fire residues, which includes 1 µl injection volume, 20: 1 partition ratio, 250 °C inlet temperature, 1 ml / min (helium), DB-5 column 30 mx 0.25 mm x 0.25 µm, initial column temperature 40 °C maintained for 2 minutes, subsequent temperature increase by 20 °C / min, final temperature 280 °C maintained for 3 minutes, MS scanning 40-300 m / z, MS quad temperature 150 °C and MS source temperature 230 °C (Turner et al., 2014).

Turner and Goodpaster (2009) used a thin layer of soil weighing 40-90 g, which was placed on the bottom of the can and formed into a square shape. 20 µl of ignitable liquid was poured onto this layer. Gasoline (87 octane), lighter fluid, charcoal starting fluid, kerosene and heating oil were used as ignitable liquids. The cans were sealed for 2-7 days at room temperature. The passive adsorption technique from the headspace was used to extract residual ignitable liquids. In this procedure, the can was opened, and the carbon strip was hung on a paper clip. Subsequently, the sealed can was placed in an oven at 85 °C for 4 hours. The can was cooled back to room temperature after 4 hours and the carbon strip was removed. The strip was then placed in a test tube and the ignitable liquid was extracted by adding 300 μl of pentane and stirring for 1 minute (Turner, Goodpaster, 2009).

3 Results and Discussion

Microbial degradation of gasoline in an experiment by Turner et al. (2014) was observed in residential, agricultural and brownfield soils. In all three soil types, n-alkanes degraded in a similar fashion in that degradation is almost complete after 7 days. In fact, no peaks remained in the chromatograms after 15 days except those attributed to the volatile aldehydes that are present in the headspace of all soil samples. In contrast, we noted differences in the ratios of the C3-alkylbenzenes depending upon soil type. For example, all profiles appear nearly identical on day 0, but on day 2 propylbenzene (peak 1 in Fig. 2) is significantly reduced in residential soil compared to 3-ethyltoluene (peak 2 in Fig. 2), while in agricultural soil and brownfield there is only a minimal reduction. By 30 d the gasoline in residential and agricultural soils experienced the greatest microbial degradation while the gasoline in the brownfield soil experienced the least. These trends may be the result of the higher levels of nutrients in the residential and agricultural soils - both soils contained higher NO_3, NH_4 and K concentrations compared with the brownfield soil. Furthermore, the residential soil contained more than twice the extractable P compared with the brownfield soil (154 versus 74 mg/kg, respectively). Another factor may be the Pb concentration in the brownfield soil (497 mg/kg), which may have impaired the activity of heterotrophic bacteria. Furthermore, Pb was found to pose a greater stress to soil microbes than did other heavy metals. Application of Pb at concentrations of >500 $mg.kg^{-1}$ caused an immediate and significant decline in microbial biomass (Turner et al., 2014).

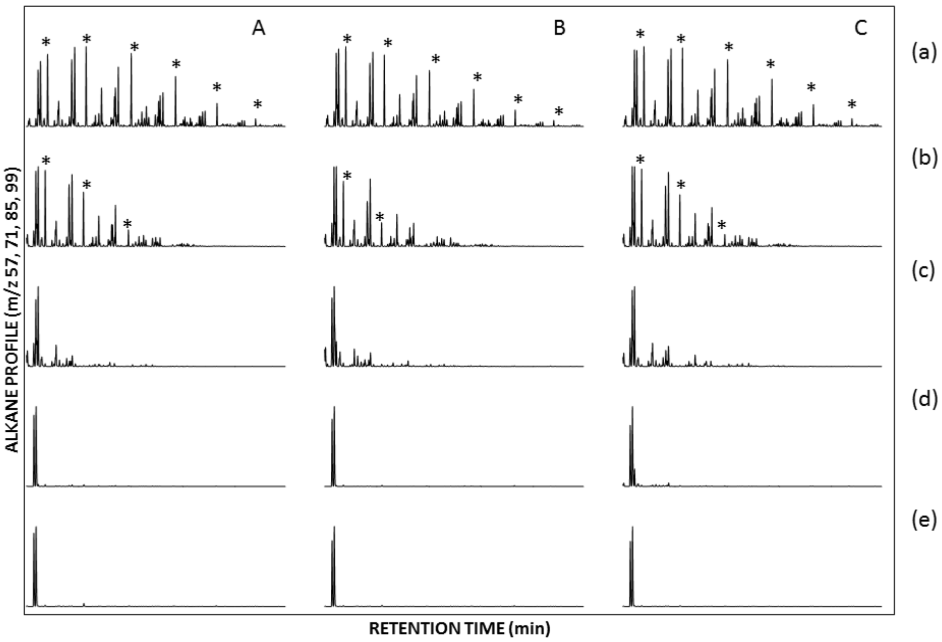

Fig. 1 Alkane profile for the soil type comparison of microbial degradation of gasoline on: (A) agricultural soil, (B) residential soil, and (C) brownfield soil over (a) 0, (b) 2, (c) 7, (d) 15, and (e) 30 days. Peaks from the homologous series of n-alkanes are marked with an asterix.

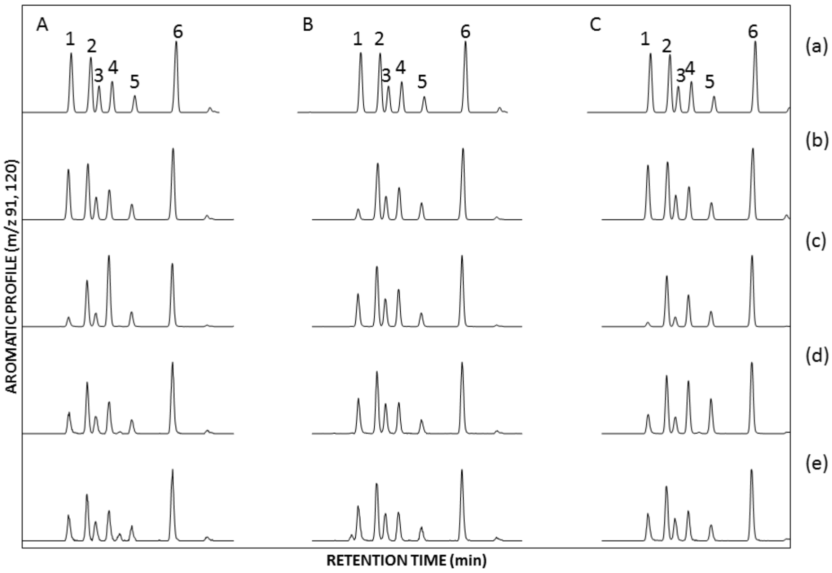

Fig. 2 Aromatic profile for the soil type comparison of microbial degradation of gasoline on: (A) agricultural soil, (B) residential soil, and (C) brownfield soil over (a) 0, (b) 2, (c) 7, (d) 15, and (e) 30 days. Peaks: (1) propylbenzene, (2) 3-ethyltoluene, (3) 4-ethyltoluene, (4) 1,3,5-trimethylbenzene, (5) 2- ethyltoluene, and (6) 1,2,4-trimethylbenzene.

Gasoline contains n-alkane and aromatic compounds, as well as branched and cycloalkane compounds. This complex mixture may be subject to pertubations such as weathering (evaporation) or microbial degradation. Therefore, in a study by Turner and Goodpaster (2009), an initial comparison of fresh gasoline and weathered gasoline was made to contrast the effects of weathering (which should depend largely on boiling point) to that of microbial degradation (which demonstrates compound selectivity) (Turner, Goodpaster, 2009).

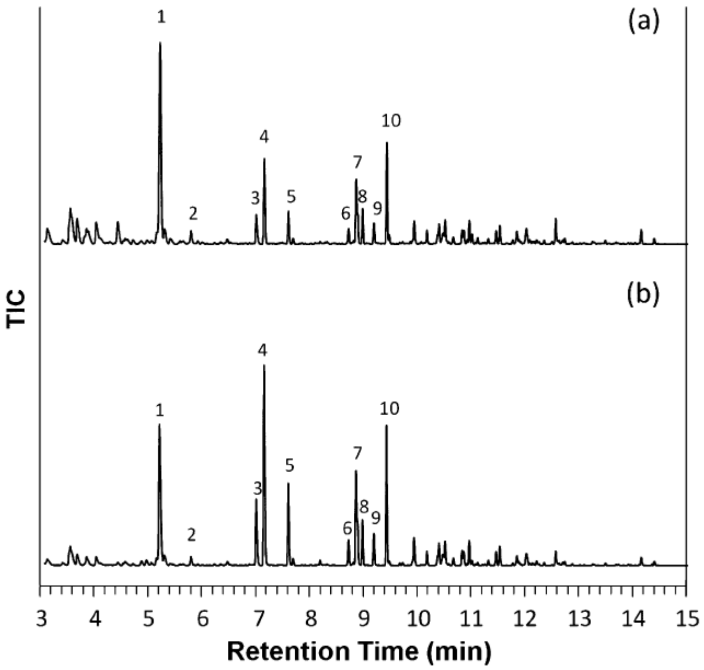

Fig. 3 Total ion chromatograms of a fresh and b slightly weathered gasoline standards diluted 0.67% v/v in pentane. Peaks: *1* toluene, *2* *n*-C_8, *3* ethyl benzene, *4* *m*- and *p*-xylene, *5* *o*-xylene, *6* propylbenzene, *7* 3-ethyl toluene, *8* 1,3,5-trimethylbenzene, *9* 2-ethyl toluene, *10* 1,2,4-trimethylbenzene

Gasoline degradation was studied over time periods extending up to 7 days. The use of a “0 day” time point allows for the effects of soil absorption and other physical/chemical factors affecting recovery of the ignitable liquid to be accounted for. Hence, the effects of microbiological activity after 2 days are readily visible, in that n-alkanes such as octane (peak 2 in Fig. 4) and decane (peak 11 in Fig. 4) largely disappear from the TIC, and the monosubstituted benzenes also show significant decreases. In addition, the peak height ratio of 3-ethyltoluene and 1,2,4-trimethylbenzene reverses. After 7 days, there are no peaks in the TIC that are readily attributable to gasoline. The peaks seen at - 4 minutes correspond to volatile short-chain aldehydes that are detected in the headspace of the soil under normal circumstances (Turner, Goodpaster, 2009).

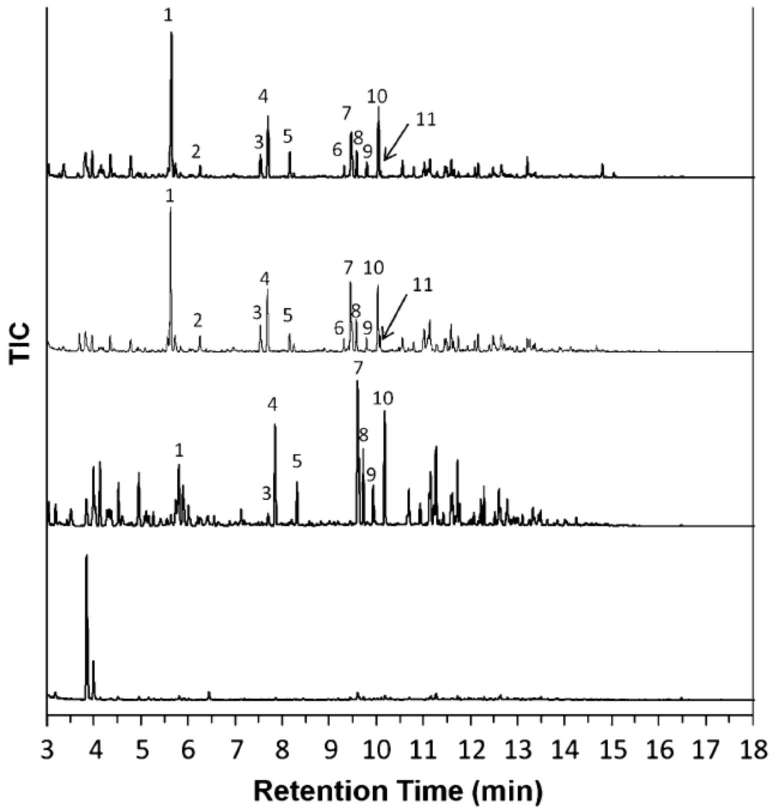

Fig. 4 Total ion chromatogram of gasoline: a standard diluted 0.67% v/v in pentane, b after 0 day on soil, c after 2 days on soil, and d after 7 days on soil. Peaks: *1* toluene, *2* *n*-C_8, *3* ethyl benzene, *4* *m*- and *p*-xylene, *5* *o*-xylene, *6* propyl benzene, *7* 3-ethyl toluene, *8* 1,3,5-trimethyl benzene, *9* 2-ethyl toluene, *10* 1,2,4-trimethylbenzene, *11* *n*-C_{10}

The potential risk of misclassifying an ignitable liquid due to microbial degradation is particularly relevant when dealing with petroleum distillates. This stems from the fact that petroleum distillates comprise branched and n-alkane compounds, the latter of which are more susceptible to microbiological attack. After 7 days, very little of the n-alkanes are present, and the resultant profile resembles that of an isoparrafin. In contrast, odorless lighter fluid comprises branched alkanes solely, which shows little to no degradation even after 7 days on soil (Turner, Goodpaster, 2009).

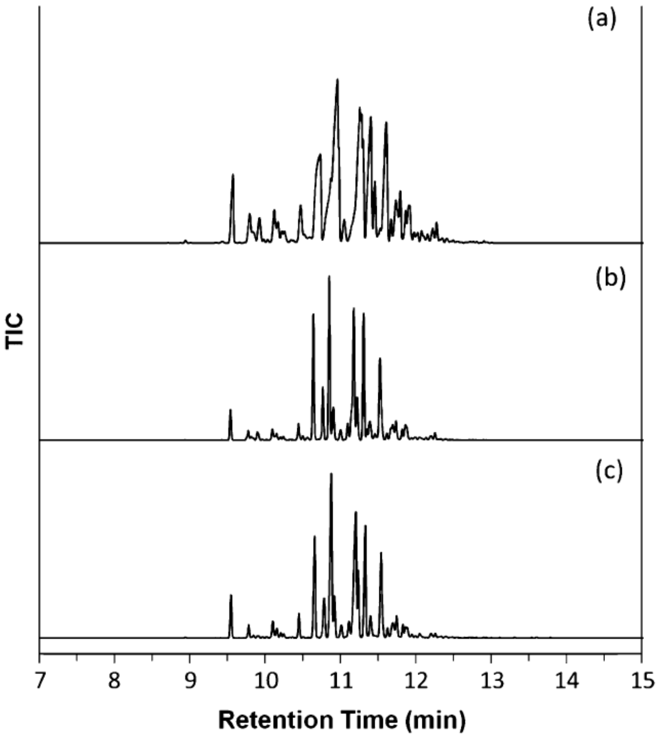

Fig. 5 Total ion chromatogram of an odorless lighter fluid, a medium–heavy isoparaffin: **a** standard diluted 1% v/v in pentane, **b** after 0 day on soil, and **c** after 7 days on soil. Peaks all branched alkanes between C_{11} and C_{15}

4 Conclusions

The ability of microbes to degrade petroleum products is a well-known phenomenon that can be used to remediate the environment. The results clearly show the need for rapid analysis of samples from the fire, for the correct identification of ignitable liquids. Microbial degradation is evident from the results for all soil types. In particular, the loss of straight chain alkanes was evident in all samples, and key compounds in gasoline were also subject to degradation. Of particular interest is the observation that bacterial degradation showed selectivity for n-alkanes composed of an even number of carbons. This represents a new type of susceptibility to ignitable liquid residues that may affect the interpretation of chromatographic data from fire evidence.

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Notre-Dame Cathedral Fire

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Short report

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Abstract

Of all the possible disasters that can damage monuments and installed exhibitions and collections, the most devastating are fires. Thus, even world-famous historical monuments have not escaped these catastrophes. The article deals with information about these fires. We describe in more detail the Notre-Dame de Paris fire and its subsequent recovery process. We have also created an overview of systemic preventive measures to protect historical and cultural monuments from fire.

Keywords: fire, fire prevention, historical building, Notre-Dame de Paris

1 Introduction

Of all the possible catastrophes that can damage monuments and buildings without monuments, and in their installed exhibitions and collections, fires are the most destructive ones. Thus, even world-famous monuments did not avoid these big and unpleasant events. Many owners as well as administrators of monuments mistakenly think that a fire cannot break out in their monument. Based on events, whether after the fire at Krásna Hôrka Castle, or in the Czech Republic after the fire at Pernštejn Castle, the all-wooden church in Guty or the wooden building Líbušín and the fires of cultural and historical buildings in other countries is paid more attention to this issue.

The Fire of the Castle of Krásna Hôrka in 2012 initiated the audit to secure the protection against fires all historical and cultural monuments in Slovakia. There are more than 12 thousand monuments that must go through this audit in our country.

The aim of this work is to point out the issue of fires in historic buildings, their subsequent ongoing renovation and overall renovation of the building, based on the example of the fire of the Notre-Dame Cathedral. This fire was also a stimulus for obtaining further information on the system of fire protection of historical and cultural monuments, as this issue is given little attention in the study of wooden buildings.

2 Analytical part

In this part of the work, we will use literary and Internet sources to analyze:

1) fires of selected historical and cultural buildings,

2) fires of Notre-Dame Cathedral in Paris

3) create an overview of systemic measures to protect historical and cultural monuments from fire.

3 Results and Discussion

3.1 Significant fires of historical objects

Fires do not avoid even the most important monuments. An overview of selected fires in historic buildings is given in Tab. 1.

Tab 1. Selected fires in historical buildings

Objects affected by fire	Date of fire	Damages caused by fire
Church of St. Michal in Prague – Czech Republic	10. 28. 2020	A large part of the church was destroyed.
Notre-Dame Cathedral in Paris – French Republic	04. 15. 2019	Destroyed roof, Sanctoid tower, damaged stained glass windows and arched ceilings.
National Museum in Rio de Janeiro – Federative Republic of Brazil	09. 02. 2018	Flames probably destroyed a collection containing more than 20 million objects, from archaeological findings after historical memorabilia.
Bank buildings in Belfast – The United Kingdom of Great Britain and Northern Ireland	08. 28. 2018	The building has suffered extensive damage at all levels, but the new wing of the building was relatively undamaged.
Church of the Assumption of the Blessed Virgin in Kondopoga – Russian Federation	08. 10. 2018	The whole church was destroyed.
Church of the Corpus Christi in Třinec-Guty – Czech Republic	08. 02. 2017	The whole church was destroyed.
Libušín at Pustevny – Czech Republic	03. 03. 2014	The fire destroyed its right part in which the artificially most valuable dining room was located.
Krásna Hôrka castle – Slovak Republic	03. 10. 2012	The shingled roofs, the exhibition in the upper Gothic palace and the bell tower burned down. The ceiling was broken in the congregation hall. Firefighters saved 90 percent of the exhibits, but the inner parts of the castle grounds remained smoky.
Industrial Palace in Prague – Holešovice – Czech Republic	10. 16. 2008	Burned the left wing of the building.
Pernštejn castle – Czech Republic	04. 15. 2005	About 700 objects burned in the depository in the former granary, including several rare paintings. A significant problem was that firefighters could not reach the third courtyard with fire with heavy equipment.
Lunéville castle – French Republic	01. 02. 2003	The entire roof and most of the chateau rooms, including the ministry halls and the chapel, burned down.
Church of St. Catherine's in Ostrava-Hrabové – Czech Republic	04. 02. 2002	The whole church was destroyed.
Chapel Bridge in Lucerne – Switzerland	08. 18. 1993	Two thirds of the wooden chapel bridge was destroyed.

3.2 Notre-Dame Cathedral fire in Paris

It is called the heart of Paris and is also the home cathedral of the Roman Catholic Archdiocese of Paris. Its name is also translated as Our Lady, or the Cathedral of the Virgin Mary or the Church of the mother of God. It was in this sacred place that the writer Victor Hugo planted the story of his world-famous novel The Temple of the mother of God in Paris. It is listed as a UNESCO World Heritage Site (Wikipedia, 2021).

The construction of the Gothic cathedral lasted from 1163 to 1345 and was started by Louis VII. At that time, Paris was only a diocese. During the Great French Revolution in 1793, the cathedral was destroyed and looted by revolutionaries, who also melted precious metals on altars. But by making it famous in Victor Hugo´s world-famous work, a voluntary collection was made, and the cathedral was saved again.

Fig 1. Notre-Dame Cathedral (before fire)

On April 15, 2019, for the first time in Paris Notre-Dame Cathedral, a fire alarm sounded on Monday at 6:20 p.m. At that time, even after a double procedure, they did not detect a fire. There were fire monitors in the cathedral, which checked the wooden structure under the roof three times a day. Notre-Dame did not have automatic sprinklers under the roof and its attic space was not divided into fire walls.

At 6:43 p.m. the alarm was activated again. The fire started in wooden beams under the roof, which is also nicknamed the forest. At that time there was a mass in the cathedral, people were subsequently evacuated. The fire then spread quickly. The temperature also reached 800 degrees Celsius and was fought by more than 400 firefighters. The fire was primarily fought from inside the structure, which was more dangerous for the staff, but reduced the potential damage to the cathedral, applying water from the outside risks draining flames and hot gases (at temperatures up to 800 ° C) to the inside. Flood cannons were used at lower than usual pressures to minimize damage to the cathedral and its contents. Aerial firefighting was not used because water falling from heights could cause structural damage and heated stone could crack when suddenly cooled. Helicopters were not used due to dangerous rising currents, but drones were used for visual and thermal imaging and robots for visual imaging and directing watercourses (Fig. 2). Molten lead falling from the roof posed a particular danger to firefighters.

Fig 2. Robot for visual display and guidance of watercourses

Fig 3. Fire extinguishing from platform

The fire, which lasted 15 hours, destroyed the tower of the building, the roof of the entire ship, the upper parts of the walls, medieval stained-glass windows, and part of the interior. However, the cause of its occurrence has not yet been precisely determined. It is assumed that the fire originated from a cigarette or electrical short circuit during reconstruction work. But there is no indication that this was intent or arson.

At 23:00, the head of the Paris fire brigade announced that the building, including the two front towers, had been „saved and preserved as a whole", but that two-thirds of the roof had been destroyed. The 69-meter-long tower, with a wooden frame covered with lead, was destroyed (Fig. 4). Although the 800-ton tower was certainly one of the most distinctive features of Notre-Dame, it was not actually part of the original building. The first tower built between 1220 and 1230 began to deteriorate after several centuries and was removed at the end of the 17th century. The cathedral was without a tower until 1859, when the builders completed work on a new design by architect Eugène Viollet-le-Duc - which, according to popular mechanics, was not an exact replica of the original.

Fig 4. Collapse of the Sanctuary tower

Weeping Parisians and stunned tourists watched in disbelief, while hell raged on the cathedral, which marks the very center of Paris. Some sang liturgical music in harmony long into the night as they stood alert, others prayed.

The French Ministry of Culture has announced that the government has set up an online portal for all those who want to contribute to the reconstruction work - more than 900 million euros have been promised to repair the cathedral from several people, companies, and institutions (Vasilko, 2019; Wikipedia, 2021; Topky, 2021; Henley, 2019.).

3.3 Status after destructive fire

The Gothic cathedral is like a house of carats: - if one side weakens, the whole side will collapse. Due to its bold height and the fact that the outer walls are weakened by several layers of windows, its structure is fragile. For months, no one could enter the cathedral due to the danger of lead dust and debris falling from the broken vault. A lone robot, controlled by a remote control, was able to clean up the burnt remains.

The first phase of restoration - conservation and protection - lasted 15 months. President Macron has appointed General Jean Louis Georgelin, the former head of President Sarkozy´s office, to oversee the work. Under the 28 pillars, wooden supporting vaults are placed, which, however, are not fixed in the stone (Fig. 6). Each of the beams had different dimensions, and therefore its mounting required maximum accuracy.

Fig 5. Notre-Dame Cathedral after fire

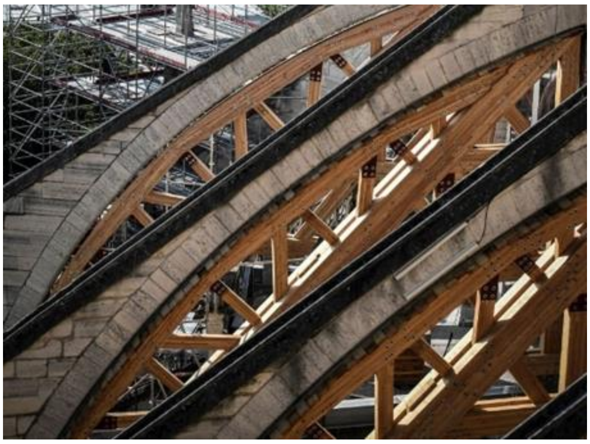

Fig 6. Wooden support vaults

Then began the most difficult and dangerous operation: the dismantling of the scaffolding, which was built in May 2018 to repair the crumbling tower (Fig. 7). This scaffold melted to form an ugly and ill-looking black mass of 40,000 metal pieces glued together. Workers with a rope approach (Fig. 8) (called cordists in French) had to collect the pieces by hand one by one, hanging on ropes high in the air. Sensors were placed under this unstable mass.

At one point, an alarm sounded. They all ran away. Disassembling this mass was like playing a huge game with a mikado, which consists of removing the sticks without disturbing the rest of the pile. Restoration work on the cathedral was interrupted twice: first when the fear of lead contamination forced all activities to stop. Workers had to wear white protective suits with masks connected to a filtered air supply. Before entering the construction site, every single worker must take a shower and change in a special cabin and keep a two-meter distance from his colleagues, which is almost impossible due to the space (TV Noviny, 2020; Regióny, 2020; Logan, 2021; Moneycontrol, 2021).

Fig 7. Wrenched scaffolding

Fig 8. Rappelling workers in protective suits

3.4 Rescued works

Some works of the cathedral were saved due to reconstructions (from fire). For example, 16 copper statues representing the twelve apostles and four evangelists to cleanse and restore them. The rooster that was on top of the tower is now on display in the Archaeological Museum and will remain there as well. He will be replaced by a replica. Fortunately, the organ and the three pink windows have been preserved, but they will require a lengthy renovation. It is particularly gratifying to know that the rose window at the southern end of the transept is intact (Fig. 9) (Logan, 2021).

Fig 9. Pink Window at South End Transept

3.5 New (old) roof design on cathedral

Just days after the fire that destroyed Notre-Dame in Paris on April 15, 2019, then-French Prime Minister Édouard Philippe announced plans for an international competition to design a new, more modern tower „suitable for the techniques and challenges of our time".

It attracted more than 200 designers from 56 countries and motivated more than 30,000 people to sign up and vote for their favorite designs. Visualizations of the designs are shown in fig. 10 and 11. Some architects have proposed to replace a wooden glass roof with a metal structure like the original, either a solar roof (Fig. 10) or a greenhouse full of plants (Fig. 11).

Fig 10. Paris Cathedral could be equipped with a new solar roof

Fig 11. Greenhouse full of plants

A team of two Chinese architects won a design competition. The design by Chinese architects, entitled „Paris Heartbeat” (Fig. 12), boasts three creative elements.

Fig 12. Proposal „Paris Heartbeat“

When designing, the new tower is interpreted into poly mirrors that subtly reflect the context along with the mirrored roof. In addition, a time capsule floats to the top of the tower every half century. The installation of magnetic levitation is made to preserve the memory of the past and reserve space for the future story. The new tower represents the memory, presence and hope of humanity. The time capsule can move rhythmically up and down, breathe, and beat along with the city.

However, these architects will have to bring their inventive designs to life elsewhere. According to the artnet News report, the French Senate has passed legislation ordering the cathedral to be „put into its last known visual state”. President Emmanuel Macron issued a statement in support of the decision, explaining that city officials should instead add a „current gesture” to the „restoration of the cathedral area”.

All renovations will be carried out in compliance with the guarantees set by ICOMOS (International Council on Monuments and Sites) (Fiolova, 2019; Zestec, 2019; Baldwin, 2019; Gutoskey, 2020).

3.6 Status after two years from fire

At present - two years after the fire (April 15, 2021), the process of restoring the Notre Dame Cathedral is being strengthened by strengthening the vault of the cathedral and preparing a future wooden structure that will support the roof. It should be ready by next summer. Most of the interior of the cathedral is now filled with metal scaffolding. To protect against the rain, an umbrella sail was installed above the through hole, where the tower once stood. The stone, metal, glass in the interior have already been cleaned. Wooden scaffolding is still being installed to stabilize the fragile areas of the cathedral vault, as well as the vaults. Stonemasons fill in the gaps and missing stones in the perimeter walls. They reinforce the most damaged areas with glass fibers.

Fig 13. Wooden beams supporting vault

The next step will be the insertion of „half hangers” (also called „centering frames”) under the six rib vaults in the choir, the northern part of the transept and the nave. Other major works are underway above the vault and under the roof. Reconstruction of a wooden frame from the 12th - 14th century, called a forest, is currently being prepared. To support the roof, there are custom-made „half-blocks” wedged under the roof and large triangular frames. One thousand of the best oaks have already been selected in several French forests. It was found that the beams from the 13th century were made of trees younger than 60 years, they were 12 m long and 30 cm in diameter. In addition, the trees were not allowed to dry for 18 months but were still used fresh after felling.

President Emanuel Macron reiterated his vision of reopening the cathedral by 2024 - both for religious purposes and for visitors to the Olympic Games, acknowledging that full restoration is likely to take several years longer (Dnes24, 2019; Plus Jeden Deň, 2021; Timeslive, 2021; Logan, 2021; Moneycontrol, 2021).

Fig 14. Current reconstruction work

Fig 15. Reconstruction work indoors

3.7 Square in front of Cathedral

Square before the Notre-Dame Cathedral in Paris was closed after the tests again revealed the high concentrations of the toxic particles of lead as just after the fire informed the Paris Police Department. Although the square has since been opened, concentrations of toxic lead particles have been regularly tested at selected locations, and local concentrations of lead dust are still higher than normal for Paris. Therefore, it was re-enclosed and to a new cleaning operation (Rfi, 2021).

3.8 What is the system of measures to protect historical and cultural monuments from fire?

The system of measures for the protection of historical and cultural monuments against fire is based on the following aspects (Jirásek et al. 2015, Decree of the Ministry of Interior of the Slovak Republic No. 202/2015 Coll. amending and supplementing Decree of the Ministry of Interior of the Slovak Republic no. 121/2002 Coll. about fire prevention):

- Fire risk analysis - this analysis is key to the fire prevention system at the monument and cultural facility and will help identify their weaknesses.
- Fire prevention - consists in setting internal regulations so that the occurrence of fire is minimized. These include regular inspections of the building, revisions of electrical installations and appliances, technical equipment, and equipment for the removal of combustion products from the building and other measures resulting from applicable regulations.
- Early fire detection - ensuring automatic fire detection by EPS system, resp. arrange regular inspections of the building at the end of working hours.
- Preparation for fire extinguishing - includes the deployment of portable fire extinguishers, hydrant systems, knowledge of fire water sources, as well as ensuring free entry and stands for units of the Fire and Rescue Corps and other components of the Integrated Rescue Corps. It is necessary to provide retraining and training of personnel in case of fire extinguishing, including the processing of fire reporting documentation.
- Measures against the spread of fire - in a minimalist sense, it consists in ensuring the principle for closing the door, especially at the end of working hours. When working on the renovation and maintenance of the building, pay special attention to ensure fire protection of the workplace. Also divide the building into fire sections.
- Preparation for the evacuation of persons and objects of a cultural nature - includes evacuation plans, but also the preparation of packaging materials and crates and regular exercises of rescue teams. This also includes the effective marking of escape routes and the installation of emergency lighting.

In practice, the method of a checklist is used to verify the condition of the fire protection system in cultural heritage sites. The form was adapted and used by British expert Stewart Kidd in 1990 (Kidd

1995). Since then, the method has been used to assess monuments in Scotland, Wales, or other Central European countries. From 2010 to 2014, up to 91 monuments under the administration of the National Monuments Institute of the Czech Republic were assessed using this method (Jirásek et al. 2015). The form consists of:

Basic information about the building - type of monument, owner / administrator and the person filling in the questionnaire and his professional focus. The following are information about the object, such as approximate age, number of floors, number of visitors per year and number of rooms.

Part A - Fire hazard assessment - aimed at an analysis of the fire hazard resulting from the materials used, internal equipment and operational activities that are carried out on the castle (Table 2).

Part B - Fire-fighting measures - aimed at identifying fire-fighting measures that reduce the risk of fire (Table 2) (Jirásek et al. 2015, Gašpercová et al. 2018).

Tab 2. Criteria for verifying fire protection system.

Part A - Fire hazard assessment	Part B Fire-fighting measures
1) Predominant building materials	1) Fire detection
2) Roof covering	2) Alarm and evacuation system
3) Roof construction	3) Automatic fixed fire extinguishing system,
4) Design of corridor walls - escape routes,	4) Regulation of combustion exhaust ventilation
5) Construction structure and division into fire sections	5) Fire equipment
6) Interior treatment of floors, walls, and ceilings of room interiors	6) Technical means for emergency units
7) Fire load of rooms	7) Doors
8) Fragmentation of the interior	8) Escape routes
9) Height of the ceilings	9) Protection against lightning
10) Possible sources of ignition	10) Building care
11) The threat of the spread of fire from the vicinity of the building	11) Building management
12) Materials of cultural objects, roofing building materials	

The result of the analysis is an overall assessment of the risk of fire in cultural heritage sites, which is the difference between the number of points in Part A and Part B. The overall assessment results from the following scale: up to 19 points = low fire risk, 20-39 points = normal fire risk, 40- 79 points = increased risk of fire, 80 and more points = high risk of fire.

By processing such an analysis, we get a picture of the fire danger of the object. This analysis can also be the basis for determining the protection of objects. The analysis is also important in planning the restoration of monuments in connection with the expansion of accessible spaces and associated collections. On April 7, 2021, it was published (Teraz.sk 2021) that by the end of 2022 the Ministry of Culture of the Slovak Republic should prepare the conditions for the establishment of a separate Fund for Monuments, a new public institution whose mission will support the protection and restoration of immovable and movable national cultural monuments. This follows from the proposal of tasks and measures within the Strategy for the Protection of the Monument Fund for the years 2017-2022 and the action plan for the years 2021-2022.

4 Conclusions

By processing this work, we have prepared a general view of the destroyed historical and cultural monuments because of the fire. We did not delve deep into history, rather we tried to describe the devastating effect of fire. At the same time, we described the course of the fire, the ongoing repairs and the interesting design process as Notre-Dame Cathedral in Paris will look like in the future. According to a statement by the French president, this cathedral should be opened to the public in 2024, when the Olympic Games will be held in Paris. However, despite this statement, all experts agree that this extensive repair of the cathedral will take much longer in terms of accuracy, safety, and quality of repair.

This situation was the impetus for obtaining information about the system of fire protection of historical and cultural monuments in our country. We introduced the method of a checklist, which they successfully use abroad and are gradually establishing in the conditions of the Slovak Republic. Preventive organizational measures have a major impact on the possibility of fire and cooperate with preventive systems based on electrical signalling devices. Unlike them, however, it costs almost nothing.

Acknowledgments

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Safety of Hiking Trails in the Malá Fatra Mts.

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Short report

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Abstract

The thesis aims to identify risky sections in the selected mountain area based on a statistical survey of the intervention activities of the Mountain Rescue Service, in the winter, when there is a continuous snow cover in the area. Based on this survey, we were able to further define the area where we assessed the current state of technical support. This work should contribute to increasing safety in the mountain area of Malá Fatra. The main points of the thesis include the characteristics of permanent danger in the mountains, the definition of the area, the assessment of the readiness of visitors in the event of an adverse event, and the proposal of measures. Based on cooperation with the Mountain Rescue Service, it was possible for statistical processing of rescue operations and subsequent expert consultation in evaluating the results.

Keywords: hiking trail; Malá Fatra; mountain area; Mountain Rescue Service; safety; tourism

1 Introduction

Mountains are an inherent part of our country and therefore there is no wonder that traffic still rises in them. In the current relaxed time and pandemic situations, a change in free time is visible. Embassed measures, closed shopping centers, cafés, restaurants and many other devices have expelled people into the nature. Some are looking for relaxation in the form of a walk in the fresh air, others like various forms of adrenaline breathtaking sports. Mountain hiking, ski mountaineering, skiing, paragliding and many other activities are becoming more and more popular. The mountains has earlier showed their strengths, also wrecking the most and most attractive athletes. And therefore the safety is paramount due to the increasing number of visitors to mountain areas on hiking trails.

The issue of work is focused on safety of hiking trails in Malá Fatra mountain area. An important part is a statistical survey of MRS intervention activity in terms of the number of interventions to specific accident situations in the area. Based on the outcome, we will assess the risk points of the areas, with the proposed measures should contribute to increasing security near the avalanche territories. The necessary part of the work in the draft measures was a professional consultation with members from the Malá Fatra Regional Center and also with the supervisor. Another objective is to propose measures to reduce these risks or full removal of safety deficiencies.

Based on the consultations with members of the MRS and experts in the area, it was also possible to consult proposed preventive, security measures that could contribute to increasing security. The proposal also includes a campaign for raising awareness of avalanche danger and a lot of else.

Characteristics of mountain massive

In terms of permanent danger in a given mountain area, it is important to know territories with avalanche dangers. Krivánska Malá Fatra belongs to areas that create suitable conditions for the emergence of avalanche. More than half of the territory form Alpine meadows, dwarf mountain pines at 30% and forest stand 20%. For better advance, we will use Fig 1, available on Avalanche.sk, which includes all the necessary data such as cumulative and tear zones, transport zones, as well as their length, slope inclination and many other attributes needed (Žiak, 2016).

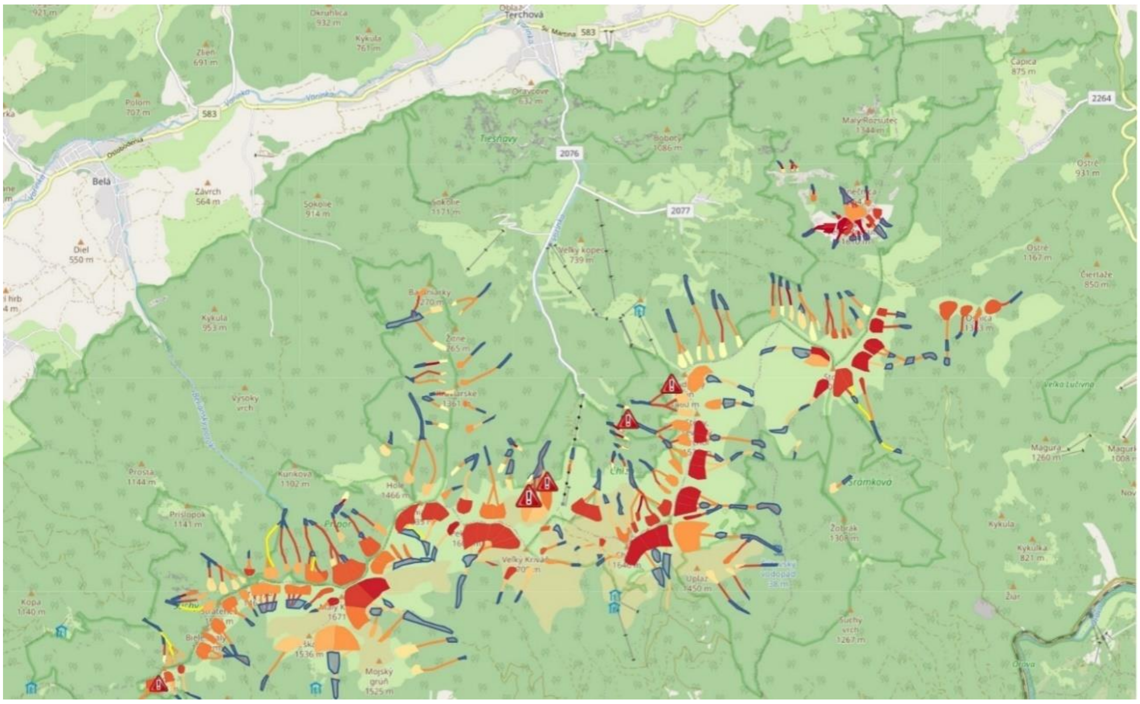

Fig 1. Avalanche map of Malá Fatra (Avalanche, 2021)

The region has high potential for tourism. Terchovská dolina has an incredibly varied natural potential that offers many options (Euro Dotácie, s. r. o., 2016). There are places that are searched for their interesting relief such as a Veľký Fatranský Kriváň, at a neighboring Malý Fatranský Kriváň, Bobota, Veľký Rozsutec and of course many others. Thus, Terchová village is a major starting point for Malá Fatra. To zoom in on the most visited parts of Malá Fatra, we will use the publicly available „Heatmap“ from the STRAVA application, see Fig 2. Heatmap is a worldwide heat map that records the user´s movement using GPS. This data is displayed on one map and therefore we can see which places or routes are most frequently used (Urban, 2018). According to the recorded data, the avalanche areas that we could see on the avalanche map of Malá Fatra are also among the popular and searched places.

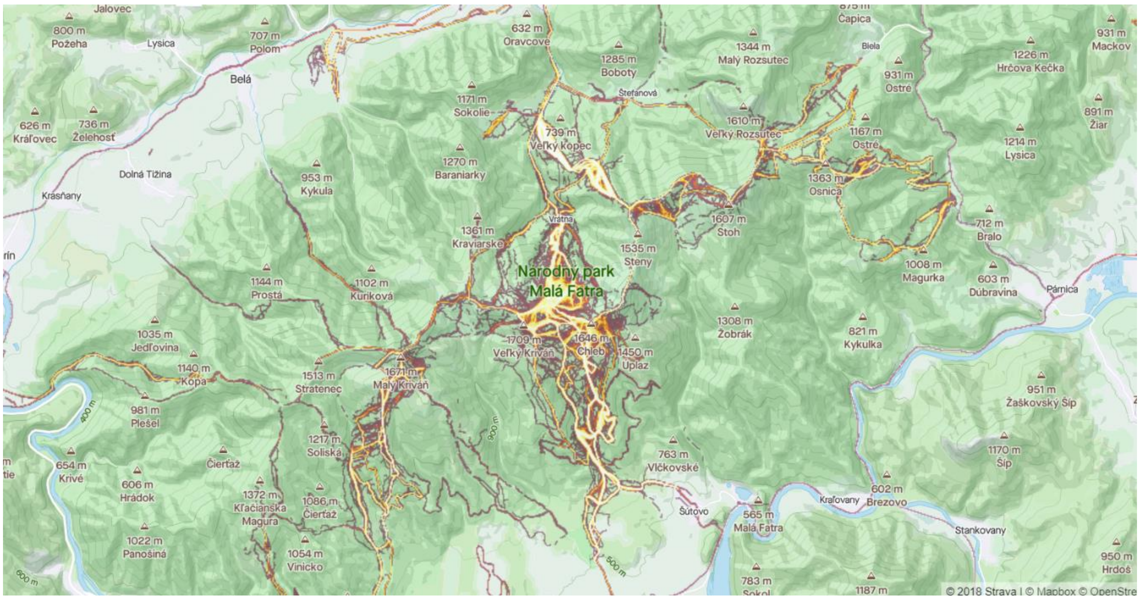

Fig 2. Most visited locations in Malá Fatra (Strava, 2021)

1.1 Winter season

The characteristic sign for the winter is snow, therefore the time-section of the intervention activity was set out in the defined area from 1 December to 1st April of the following year. There is a continuous snow layer in this period. Rescuers with professional competence for rescue activity in avalanche and also specialists perform regular snow cover measurement on eight observation sites. The results serve to assess the stability of the observed snow cover. Avalanche forecast is updated every day, we divide it into general and individual forecast. The general avalanche forecast is given based on the collected data of the Avalanche Prevention Center and informs us with the media on the current situation in the mountains. However, the degree of avalanche danger is published for the entire mountain area, not for its individual parts. It is for this reason that it is also necessary to make an individual avalanche forecast. It is an analysis of the area in which we are currently operating, or in which we plan to carry out activities. Avalanche Prevention Center of Mountain Rescue Service (APC MRS) cooperates with domestic avalanche level organizations such as high school technical and science focus, or Slovak Hydrometeorological Institute (SHMI). In addition to the organization mentioned, International Commission for Alpine Rescue (ICAR), also cooperates with Association of European Avalanche Services (Janiga et al., 2010).

1.1.1 Marking and technical security

The ridge of Malá Fatra is labeled with a belt tourist brand with two white and one red belt in the middle. The ridge relief is significantly rugged, sharp, and diverse shape. For longer routes without turns and intersections, comfort signs are also used here, which are within 250 meters of each other. Marker pins are used in places where there are no suitable objects for placing markers. These pins are painted with a deep yellow color, which ensures good visibility, and their height is 1.5 meters. When crossing sidewalks, there are signposts that carry the function of an information element. Typically, the direction of the journey also occurs with the expected route time (Guldan et al., 1990).

In winter, bar marking is used annually at the ridge and facilitates the orientation especially in inclement weather such as a mist or dense snow. Bar marking is before winter controlled by MRS that oversees it, damaged and missing rods need to be replaced with new (Bárdy, 2021).

1.1.2 Security measures near the avalanche territory

Before the winter season, the avalanche boards are put into the terrain that warn visitors that the avalanche terrain begins behind the table. These boards are specifically on the edge of the Veľký Kriváň, in the Sedlo pod Suchým and in Príslop pod Suchým. Of course, the survey of the terrain is also carried out by the members of the MRS themselves, when they monitor, for example, avalanches fallen and the condition of the bar markings. The snow cover survey is usually carried out two to three times a week, depending on the amount of new snow fallen. These data are then sent to ACP MRS, where according to the data they determine the degree of avalanche danger (Bárdy, 2021)

1.2 General movement principles for avalanche danger

The first basic rule is „ don´t go alone"! If we are alone, we risk not having anyone to help us in the event of an avalanche. On the other hand, large groups are not recommended either. If there is a group of skiers in a steep gutter, it is necessary for each of them to go down alone. When climbing a steep slope, it is recommended to adherence larger distances (Spolok horských vodcov, 2006).

Secondly, there is no need to underestimate your mandatory equipment, an integral part of which is an avalanche search device, avalanche shovel and probe. Before initiating any activity in the mountain environment, it is advisable to prepare adequate gear in relation to current terms. Checking the functionality of mandatory gear and putting the search apparatus into operation during the avalanche threat. Terrain's inspection - we plan our route with ridges, rugged slopes with terraces, trees and we try to avoid gutters and slopes that have a continuous snow cover (Toma et al., 2007).

In terms of security, the **International danger avalanche scale** is known. This scale specifies us possible mechanical or spontaneous emergence of an avalanche or place where the expected avalanche danger is.

Tab 1. International danger avalanche scale (author, according to: Lizuch, 2009)

Grade	**1.**	**2.**	**3.**	**4.**	**5.**
Risk	Small	Slightly	Increased	Big	Very big
Snow Layers Stability	Stable and well paved.	In extreme, steep places only slightly paved.	On many extreme places slightly paved.	Slightly paved on most avalanche territories.	Weakly paved and unstable.
Probability of falling avalanche	It is not expected. The exception is a small snow slides.	Possible landslides in mechanical load in extreme slopes.	The occurrence of avalanches at mechanical load in extreme slopes and possible spontaneous emergence of avalanche.	A spontaneous emergence of secondary and large avalanches.	Spontaneous release of large avalanches to less steep slopes.
Restrictions	Without	Not over 40°	Not over 35°	Not over 30°	NO!

2 Methods

The object of the research is mainly the intervention activity of the MRS, while we will examine the 5-year period of interventions based on information provided by members of the Regional Center of MRS Malá Fatra. In this work we will point out not only the current state of hiking trails in terms of safety, but also the readiness of visitors who are looking for recreational or adrenaline winter sports in the area.

The form of inquiry was used in the work, which belongs to the basic methods. Using the given method, we determined the readiness of visitors for undesirable events of the assessed area. The questionnaire was created via Google Form, which involved a total of 160 suitable respondents, which created 2400 input data for further statistical processing. Based on the survey, it is possible to find out the most visited localities, the most numerous sports activities, completed courses, ability to solve selected situations and much more. The methodology is based on a statistical survey. Statistical scientific discipline deals with the study of mass social phenomena and processes, it can also be phenomena such as biological or technical. Statistics mainly examine the quantitative side of the given phenomena, but we cannot put their qualitative side in the background. Typical features for statistics are that it deals with variable features, is expressed using numbers and finally uses computational techniques (Novák, 2008).

We used the possibility of personal consultations with experts from practice, which we could rank among the most effective sources. Based on their knowledge, experience, and skills, they provided us with the necessary information and the opportunity to consult on the proposed security measures.

3 Results and Discussion

We have addressed the Regional Center of MRS Malá Fatra for the statistical project, where they provided us about intervention activities in Krivánská Malá Fatra from 2014 to 2020. We have defined for the time period from 01.12. until 01.04 of the following year, because in the given time, the snow cover is in the mountain area. As this work deals with safety on hiking trails in the winter and our selection was narrowed down to the intervention activity in the open terrain (outside the slopes) were recorded 80 interventions, which in terms of examined statistical features shows 640 input data.

3.1 Definition of area

Statistical question: In which area have the most interventions been made?

Statistical character: area

Character characteristics: verbal **-** quantity

Used method and its justification: Simple sorting, which we use when sorting a word character that has less than 15 variations.

Selecting graphic and table tools: When solving a given statistical problem, we will use a table for simple sorting. The graphic tools use a bar graph and a pie chart (percentage distribution). Interventions that were carried out outside the ridge are also included according to the sides of the world as the northern and southern part, according to the Steny za Hromovým.

Note: Due to the large number of variations of the examined statistical feature, we decided to assign a sub-area to individual areas based on the following criterion:

a) We imaginarily divided the ridge of Malá Fatra in half, while the dividing point is in Snilovský sedlo. Therefore, the individual places where the intervention activity was carried out on the ridge are divided into eastern and western parts according to the sides of the world.

b) Interventions that were carried out outside the ridge are also included according to the sides of the world as the northern and southern part, according to the Steny za Hromovým.

Tab. 2 Distribution of intervention activities by area

Subarea	Number of interventions		Cumulative abundance	
	Absolute	Relative	Absolute	Relative
South part MF	11	13,75	11,00	13,75
North part MF	22	27,50	33,00	41,25
East part MF	15	18,75	48,00	60,00
West part MF	32	40,00	80,00	100,00
Total	80	100,00	x	x

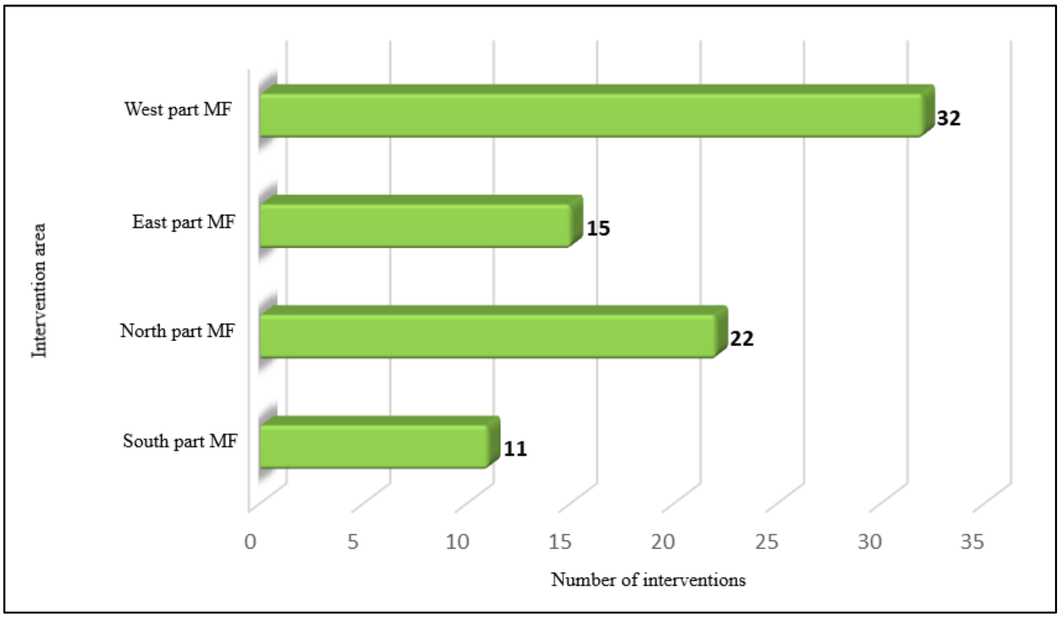

Fig. 3 Displaying the number of interventions in the selected area

Interpretation of the result: Distribution of intervention activities by area - shows the number of interventions in individual parts of Malá Fatra. The fewest interventions were made in its southern part, with 11 interventions. On the other hand, most interventions were recorded in the western part, these are exactly 32 rescue operations from the total intervention activities of members of the Malá Fatra MRS.

3.2 Assessment of the intervention activity in terms of the cause of the intervention

Statistical questions: What is the most frequent cause of intervention and in which area?

Statistical character: cause, area

Character characteristics: verbal - quantity

Used method and its justification: Sorting in a combination of two word characters. We will use the given method because we need to see the absolute number of individual causes of the trip in the assigned subarea.

Selecting graphic and table tools: We will use a contingency table of empirical abundance and we will use a bar graph from graphic tools.

Tab. 3 Contingency table of empirical abundance

Subarea	Avalanche	Missing	Falling	Injury LL	Injury UL	Spine injury	Stuck	Obstruction	Health problems	Total
South part MF	0	0	0	3	1	0	0	3	4	11
North part MF	0	0	3	4	0	0	6	2	7	22
East part MF	0	1	0	1	0	0	6	5	2	15
West part MF	1	1	0	2	2	1	10	6	9	32
Total	**1**	**2**	**3**	**10**	**3**	**1**	**22**	**16**	**22**	**80**

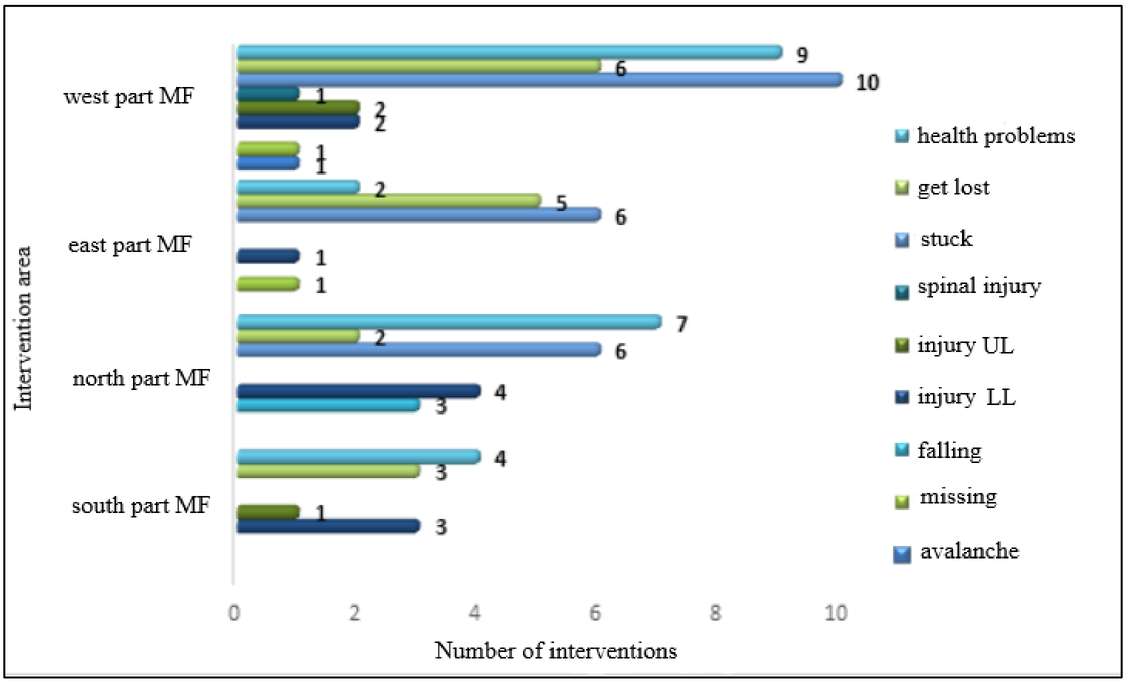

Fig. 4 Display of the number of accidents in each area

Interpretation of the result: As can be seen in Tab 3, the most common cause of MRS intervention is stuck with health problems, and any changes in the human body, such as heart attack, nausea, and others considered as health problems.

3.3 Additional information

Six deaths occurred during the interventions, and not a single fatal accident occurred in the southern part and in the other parts in the same way, two at a time. Therefore, we did not rank this statistical feature as representative and we focused on more numerous causes than mentioned above, namely stuck, missing and health problems.

Tab. 4 Intervention action in terms of accidents

Subarea	Injuries		Total
	Fatal	Other	
South part MF	0	11	11
North part MF	2	20	22
East part MF	2	13	15
West part MF	2	30	32
Total	**6**	**74**	**80**

Summary: Safety is important in every area, the complexity of rescue operations is difficult to assess, as each one of them is something specific. The force of nature is unpredictable and even if all safety measures are observed, there is a risk of injury, missing or other undesirable event. The greatest danger in winter is avalanche, but also a strong gust of wind associated with snow (Bárdy, 2021). The statistical survey of MRS intervention activities served us to define a part of the Malá Fatra mountain area. The area that we will deal with in the next part and assess its current state in terms of safety is the western part of the ridge of the mountain massif. According to the results of the survey, the most frequent trips in this area took place, with the main cause of the intervention being missing, getting stuck or health problems. The avalanche accident in number 1 occurred in the western part, but it is not a representative figure.

Tab. 5 Identification of risk points in the selected area

Year	Number of rescued	Nationality	Intervention area	Subarea
2014	1	SK	Starý hrad	West part MF
2014	1	SK	Veľký Kriváň	West part MF
2015	1	SK	Chata pod Suchým	West part MF
2015	1	CZ	Veľký Kriváň	West part MF
2015	1	SK	Priehyb	West part MF
2016	1	PL	Biele Skaly	West part MF
2016	4	CZ	Biele Skaly	West part MF
2016	1	SK	Chata pod Suchým	West part MF
2016	1	SK	Malý Kriváň	West part MF
2016	1	CZ	Veľký Kriváň	West part MF
2016	4	SK	Pekelník	West part MF
2016	2	CZ	Snilovské sedlo	West part MF
2016	1	SK	Starohradská dolina	West part MF
2017	1	SK	Veľký Kriváň	West part MF
2017	1	CZ	Veľký Kriváň	West part MF

2017	2	CZ	Pekelník	West part MF
2017	6	SK	Malý Kriváň	West part MF
2017	3	SK	Malý Kriváň	West part MF
2017	5	CZ	Malý Kriváň	West part MF
2017	2	PL	Snilovské sedlo	West part MF
2018	1	CZ	sedlo Bublen	West part MF
2018	3	CZ	Pekelník	West part MF
2018	8	SK	Malý Kriváň	West part MF
2018	5	CZ	sedlo Bublen	West part MF
2019	1	SK	Veľký Kriváň	West part MF
2019	3	CZ	Pekelník	West part MF
2019	3	PL	Snilovské sedlo	West part MF
2019	1	SK	horná stanica Vrátna	West part MF
2019	1	SK	Chata pod Suchým	West part MF
2019	1	SK	rozhľadňa Špicák	West part MF
2019	1	CZ	Snilovské sedlo	West part MF
2020	1	SK	Hoblík	West part MF

As we can see, there were numerous trips to Chata pod Suchým, Veľký Kriváň, Malý Kriváň, Biele Skaly in the selected area, several rescue operations also took place in Snilovské sedlo or Pekelník. From the given table we can see that we have several nationalities represented here, from which we can conclude that the Malá Fatra National Park is being searched and popular not only with locals.

3.4 Evaluation of visitor readiness

Avalanches are affected by several factors, from solar radiation, wind direction and speed, air temperature, rainfall intensity, slope and exposure, snow cover humidity to the human factor. It is for this reason that we focused on assessing the readiness of visitors for undesirable events, because we can also influence the formation of avalanches by our behavior and actions (Lizuch, 2009).

We used the inquiry in the form of a questionnaire and focused on the following main questions:

- What are the most frequently performed sports activities in the area?
- What knowledge and skills do visitors to the assessed area have when performing sports activities in selected situations?
- What equipment do they use in their activities?
- What is the satisfaction with the technical provision of hiking trails in the selected area?

In our survey, 160 respondents involved through the public online group of skialpinism and climbing, while the main condition was performing sports activities in the selected area. We assumed that the addressed group, which moves in an area with increased avalanche danger, will be able to respond to selected situations such as reporting an accident on the MRS line, or IRS, which is a reaction if we witness an avalanche accident.

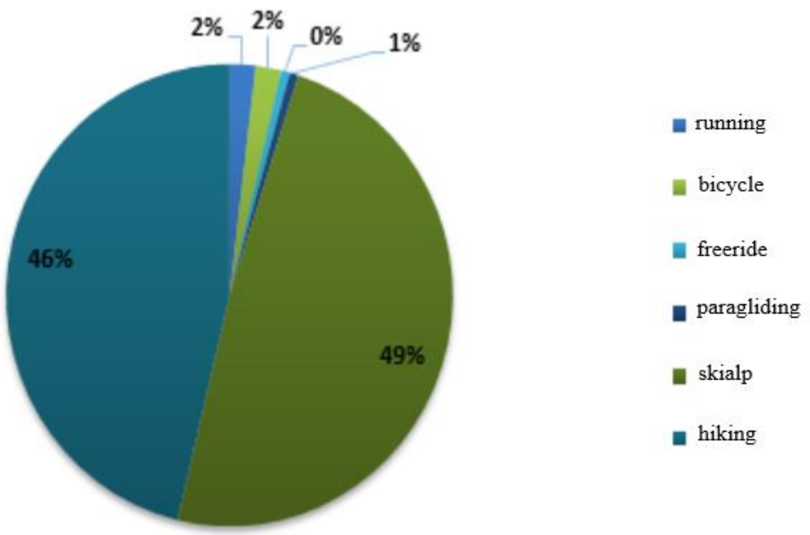

Fig. 5 The most frequently performed sports activities

From the previous graph the most frequently performed sports activity in the selected area is ski mountaineering, represented by 46%. Skiing in extreme, steep, gutters pose a high risk of avalanches and the necessity in this activity is mandatory equipment, basic knowledge of avalanche danger and skills.

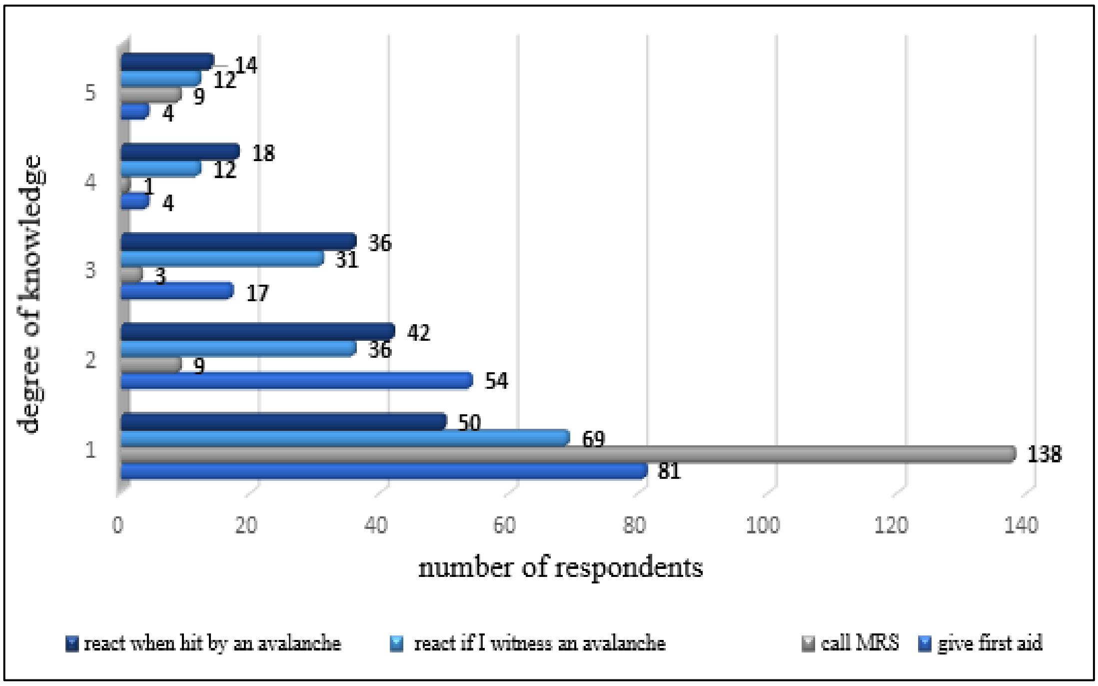

Fig. 6 The ability to respond to selected situations

From that graph, we can see that only 50 interviewees can respond to the avalanche, 69 respondents can respond if the avalanche is witnessed. The first aid can give 81 respondents and the largest number of 138 people can report the situation at the MRS, or IRS. Another criterion for assessing readiness was completed courses, while the representation of courses suitable for the mountain environment was diverse. We also had a member of the MRS, a voluntary member of the MRS, or an International Mountain Leader (UIMLA).

Another criterion for readiness evaluations were graduated with courses that are needed in the alpine environment. These courses increase the knowledge of possible danger and increase the chances of survival in the event of an unfavorable event.

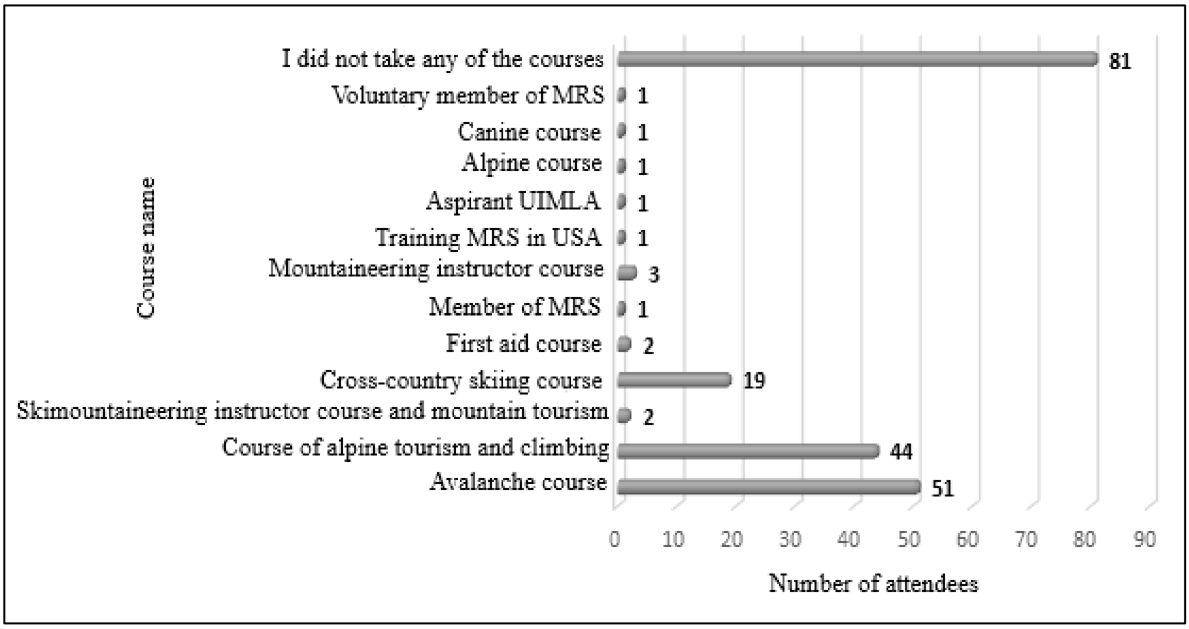

Fig. 7 Completed courses

From the following graph we can see how many visitors from the interviewed group wear mandatory equipment. The first-aid kit has the largest representation, for the administration of first aid. Furthermore, the most used are the mattock, the probe, and the avalanche search system.

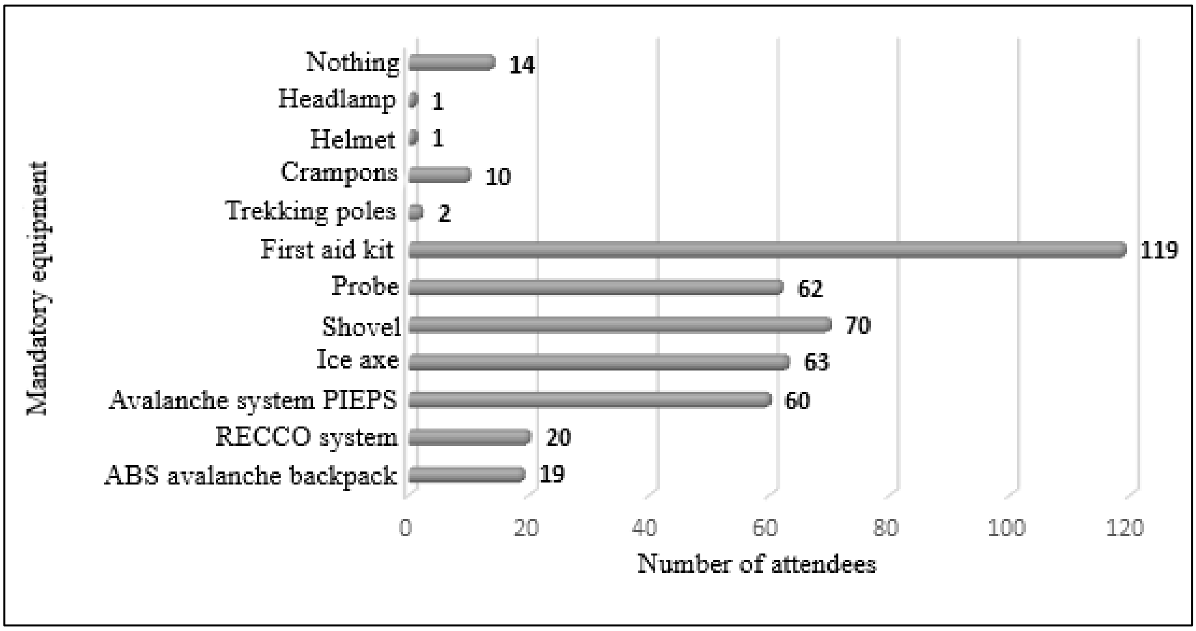

Fig. 8 Mandatory equipment

Satisfaction with the technical provision of winter hiking trails can be interesting. As many as 96% of respondents are satisfied with the technical security and dissatisfaction is only with 4% who think that the security is not suitable. We can say that safety is sufficient, so the human factor plays a role in accidents.

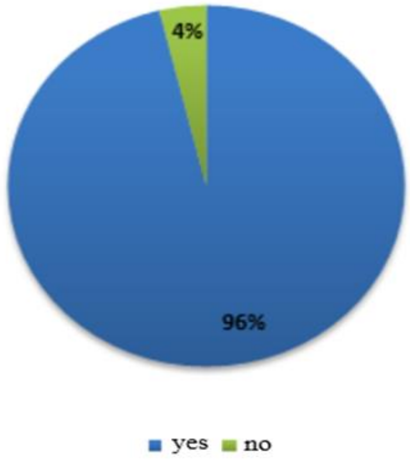

Fig. 9 Satisfaction with technical security

3.5 Suggestions and recommendations

As we have already mentioned, mandatory avalanche equipment is a priority for every ski alpinist. When hit by an avalanche, it can save our lives, or we can use it to help save a buried friend. It would therefore be appropriate to introduce a precautionary measure, such as in neighboring Austria, namely a fine for missing avalanche equipment such as PIEPS, avalanche shovel, probe of 300 EUR. It is the amount for which we can secure this basic equipment. It is also suitable to have an ABS avalanche backpack, which is increasingly part of the equipment, this backpack is one of the active elements of the equipment and works on the principle of a life jacket when drowning in water. When activating the backpack, an airbag is created, in the form of a large pillow, which perfectly protects our head and neck from mechanical damage. Another sought-after element is the RECCO system, which is built into a ski jacket, trousers, or other clothing, but these are already more financially demanding items. Nature is unpredictable, so it is necessary to have respect for it and it is important to always be prepared regarding the current situation in the mountains (Bárdy, 2021).

From the point of view of the high number of visitors in Malá Fatra even in the winter and the occurrence of avalanche danger, it would be appropriate to build a PIEPS CHECKPOINT control station. This project is in the initial phase of development, control points for the functionality of avalanche search engines are so far located only in the High Tatras in four places. In our case, they could be built in the main starting nodes, such as in Fig 16, where the lower station is cottage Vrátna (1) and Zajacová (2) (Bárdy, 2021).

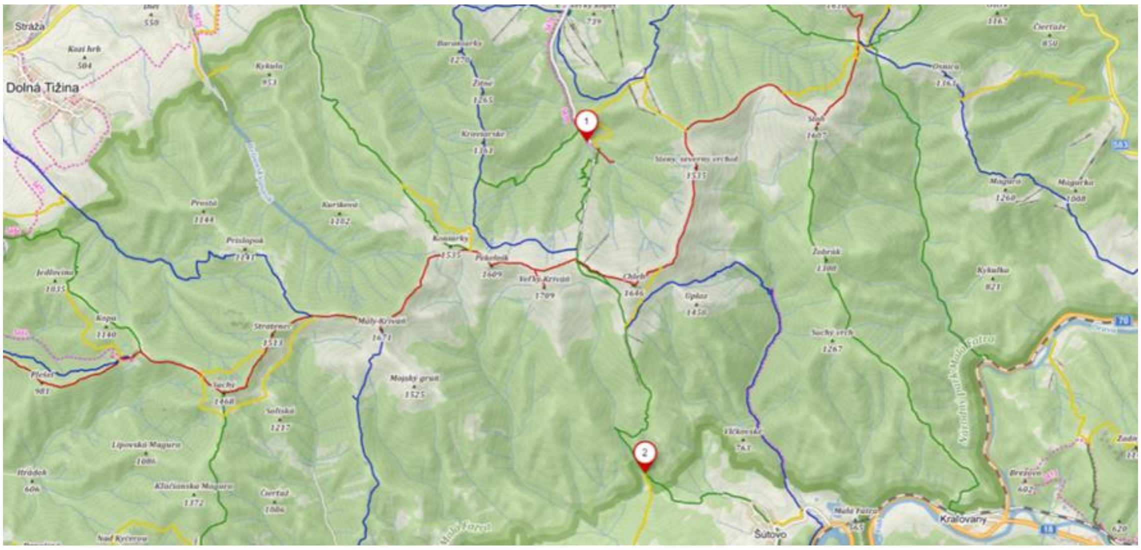

Fig. 10 Location PIEPS CHECKPOINT in selected areas (Mapy.cz, 2021)

In terms of preventive measures, we also consulted the controlled firing of avalanches, or technical support for the diversion or capture of the released avalanche. The mentioned avalanche shots in the Malá Fatra mountain area are carried out on the Oštiepková mulda, where the resulting snow prevails can endanger the ski slopes. In our assessed area there is no threat to the transport infrastructure, settlements, or ski slopes, therefore these controlled shots are not performed (Bárdy, 2021).

From the point of view of a statistical survey of the evaluation of the readiness of mountain visitors for adverse events, we would certainly include among the proposals campaigns that would serve to raise awareness of avalanche danger, mountain insurance, MRS activities or the need for mandatory equipment. It could be a suitable way; it is a way of addressing the public. Advertising is often associated with certain financial costs, but this type of visibility was used by MRS in cooperation with GENERALI Poisťovňa, a. s when launching the mobile application MRS. Another way is a bumper, a specific type of ad that will appear on YouTube in the form of a short video or animation. Besides that, we could use information posters, cards, or banners, whether static or animated. These proposed campaigns should be engaging, concise and should carry the essential information we want to point out (Karkuš, 2016).

4 Conclusions

Due to the increasing number of visitors to mountain areas and the more frequent search for adrenaline and winter sports, the risk of avalanche accidents also increases. This can be caused by several factors. From factors that directly affect the formation of avalanches, or the human factor that can affect the formation of avalanches by its indifference to safety measures, ignorance, or inexperience. From the information obtained, not every visitor care about their safety, or the safety of their companions, and therefore raising awareness of avalanches is a priority.

The basic goal was to assess the current state of the selected area, evaluate the readiness of visitors and then propose changes in the marking of winter hiking trails near avalanche areas. As we found out during the expert consultation with the members of the fire brigade Malá Fatra, the winter bar marking leads outside the avalanche area, while the summer tourist marking is invalid in the winter, so the proposals for changes to the marking are unfounded. Avalanche boards are placed on the ridge of Malá Fatra. The condition of the snow cover and the degree of avalanche danger is regularly updated on the official MRS website. Based on expert consultation with members of the MRS or experts from practice, we were able to evaluate the proposed safety measures such as building PIEPS CHECKPOINT stations in the starting nodes, building weather stations, building technical equipment to divert or capture the released avalanche and controlled avalanche blasting. Not all these proposals were accepted as they would not have the expected informative value. Despite some negative opinions, we believe that stricter security measures need to be laid down.

In conclusion, we will just remind you that there is no need to overestimate your strength or underestimate the power of nature, and in case of any questions about the current situation in the mountains, you can just inform the Regional Center of MRS in Malá Fatra, or their official website. It is also good to think about the general principles of safety and we need to think about mountain insurance, which can save us the financial inconvenience of MRS intervention. Despite taking some of the courses mentioned above, we are not heroes, and it is necessary to go to the mountain environment with respect.

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Identification and Comparison of Key Parameters of Forest Litter and their Effect on Fire Initiation and Spreading

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Short Report

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Abstract

From the point of view of future prognosing the periods with higher danger of fire initiation and identification of potentially fire dangerous areas, it is important to know the key parameters of fuel which have a significant impact on fire initiation. The main aim of the paper is identification and comparison of parameters of litter of selected tree species which have a significant impact on fire initiation, propagation and further spreading. The most significant key parameter in identification of forest fire danger the fine fuel moisture content. The object of the study represents the biomes of boreal conifer forests and deciduous forests. The result of the study indicates that higher litter moisture content significantly reduces fire initiation potential, intensity and subsequent fire spreading. Pine litter, due to small measures of needles, produces well-rammed and non-aerated litter. This litter can accumulate more than double the volume of water in comparison with deciduous litter. Consequently, in conditions with high humidity, it is very difficult to catch a fire. Deciduous trees produce aerated litter (containing an oxidation element), which can accumulate less water, it dries off better, and for that reason, in conditions with higher humidity the deciduous tree litter catches fires easier. In case of dried fuels, the amounts of initiatory energy required for setting coniferous and deciduous vegetation on fire do not differ significantly. Hard dried oak litter is the highest fire danger, and it is the easiest to catch fire. Pine litter is characterized, due to the high volume of resin and vaporizing substances, with much higher amounts of heat release rate, cumulative heat released, combustion heat and heating power, therefore it poses the highest danger from the point of view of fire intensity and fire spreading.

Keywords: climate change; fire danger; forest fire; fuel moisture; litter; forest fires.

1 Introduction

Climate change, as a change in the state of climate variables, has often been seen as a future threat, but it is currently one of the biggest environmental problems. The society strives not only to adapt to these changes, but especially to mitigate them. (Minďaš et al., 2011) Climate change poses a huge threat, stressful situations, and fear for the lives of people around the world. Many people face the significant impacts of climate change, such as storms, floods, global warming, extreme rain, and dry and extensive forest fires, which have caused considerable damage in recent years. (Hoştut et al., 2020) The number of such extreme weather events is currently growing in Slovakia as well. In our territory, those are mostly the floods, landslides, heat, prolonged droughts, and the growing risk of fires. (MINV, 2021) As climate change intensifies, the need to develop vulnerability assessments and adaptation strategies is becoming more urgent. Reliable and sound prognoses are essential for accurate risk assessment and the development of effective reactions and measures. (Marshal et al., 2019)

Due to global warming and rising average temperatures, the frequency and duration of periods of increased fire risk are expected to increase, and thus the number, extent and severity of fires will also increase. (Marchal et al., 2019) Particularly high temperatures and recurring droughts over the last decade have led to severe periods of fire in forest ecosystems around the world, e.g., in Australia, Sweden, Chile, Greece, the USA and Canada. (Gaboriau et al., 2020) Fuel, weather and topography are the three factors that make up a forest fire environment and determine its behaviour. The initiating source itself is the fourth factor that reacts with others. (Santoni et al., 2020) Predicting the effects of future climate change on fire occurrence requires an understanding of the effects and interactions of temperature and precipitation on fuel moisture content dynamics. As the average temperature increases, fuels will be overdried, which will not only become more prone to ignition, but may also support more intensive fire spreading. (Flannigan et al., 2015) The moisture content of the fuel is thus a key parameter in determining the danger of forest fires.

Surface fires are among the most common fires in the natural environment, due to the availability, moisture content, and volume of fuel. Surface fires burn on the surface and consume fuel as e.g., litter. (Heward, 2019) Litter is a mixture of undecomposed and partially decomposed materials, on ground fallen material such as leaves, needles, and branches. They create forest bed, which strongly influences the ignition and spread of fire. (Burton et al., 2020) Tree species composition of a stand has a significant effect on litter composition. The physical properties, chemical properties, size, and shape of the particles significantly affect the dynamics in moisture content of the litter and its flammability. The properties of deciduous and coniferous forests litter differ from each other. (Cornwell et al., 2015)

From the point of view of the future predictions of periods with an increased danger of fires and the identification of position of possible fires, it is important to know the key fuel parameters that affect the fire behaviour. The main goal of this study was the identification and comparison of the parameters of selected tree species litter, which have a significant impact on the fire behaviour, especially on its initiation, propagation and further spreading.

The aim of the study was the identification and description of key parameters of pine, oak and beech litter and their impact on the initiation and propagation of a fire. Individual types of forest litter were also mutually compared.

The object of the study was biomes of boreal coniferous forest stands and deciduous broad-leaved forest stands occurring in these biomes and litter of the tree species existing on the composition of those forests. Among those tree species belonged: Masson's pine (*Pinus massoniana*), Scotch pine (Pinus sylvestris) and longleaf pine (*Pinus palustris*) as representatives of coniferous stands, and European oak (*Quercus robur*), sessile oak (*Quercus sessilis*), iron oak (*Quercus stellata*), sawtooth oak (*Quercus acutissima*) and European beech (*Fagus sylvatica*), as representatives of deciduous stands.

2 Material and Methods

To achieve the goal of the study, we used several scientific methods, namely analysis, synthesis, and summarization of knowledge as well as the method of comparing.

After finding the appropriate literature sources, we performed its detailed analysis to determine its contribution to our study. Subsequently, we selected an essential information from the literature and data that were suitable for achieving the goal of our study.

After analysing the scientific literature, we combined selected information from several and summarized it. Using synthesis, we combined information and data of individual authors and their views on the issues addressed.

In the results, we summarized the data and key parameters of the litter of individual trees species, which created the subject of the study.

We compared the key parameters of the litter of individual tree species and derived basic differences between them.

3 Results and Discussion

Fuel moisture content is an important and driving factor that determines the behaviour of a fire. Determining the water content that a fuel can accumulate expresses the moisture holding capacity. This capacity is mainly affected by the weight, dimensions, and composition of the fuel. The values of moisture holding capacities of the litter of individual types of forest stands differ from each other, but there is a significant difference in the values of the capacity between the litter of coniferous and deciduous trees. Fig 1. shows the values of the moisture holding capacity (l / m^2) of European beech, sessile oak, and sawtooth oak litter, as representatives of deciduous stands, and the moisture holding capacity of Masson's pine litter, as a representative of coniferous trees.

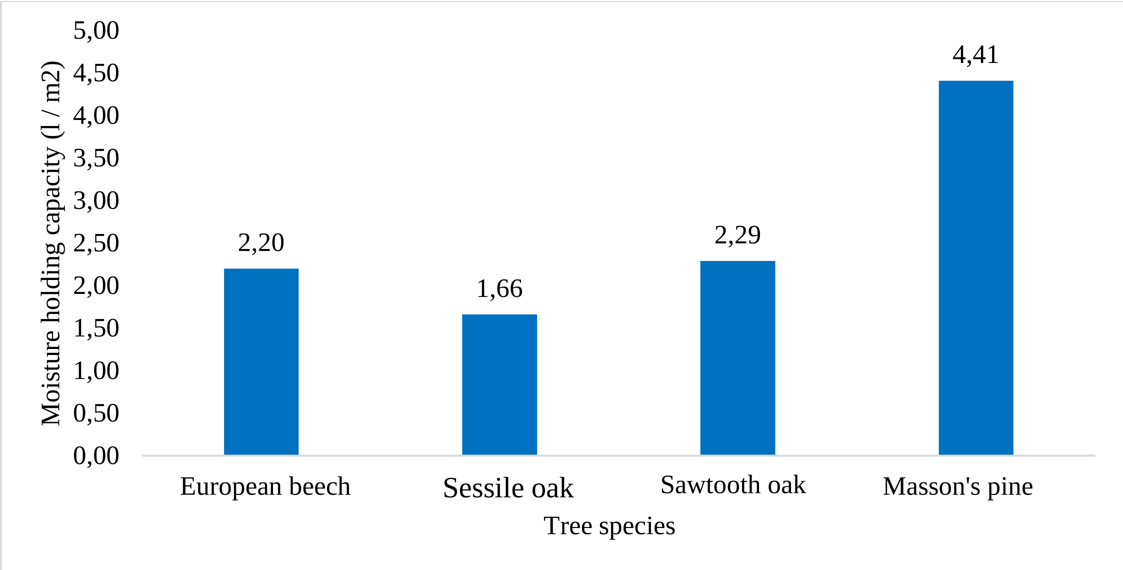

Fig 1. Moisture holding capacity values of different types of forest litter

The lowest value of moisture holding capacity (1.66 l / m^2) showed the litter of sessile oak. This was followed by a litter of European beech with moisture holding capacity of 2.20 l / m^2. The litter of sawtooth oak had a slightly higher value of the moisture holding capacity (2.29 l / m^2). In general, deciduous trees showed very similar values. There was a significant difference in the case of Masson's pine litter, which showed a value of litter moisture holding capacity of 4.41 l / m^2, which is more than twice the value of the deciduous trees.

The volume of water that the litter can accumulate has a significant effect on the initiation and at the same time on the subsequent spread of the fire. The more water the litter contains, the more difficult it is to ignite, because the initiating energy is first consumed to heat and evaporate the water, and then to heat the fuel to the ignition temperature and to form gaseous products. Thus, with a higher moisture content of the fuel, a higher initiation energy is required, and the risk of fire is significantly reduced. In the case of fires that have already occurred, the spread of the fire when a high-moisture content fuel is reached may be stopped if the fire does not have sufficient energy to dry out and subsequently initiate the moist fuel. Moisture content thus significantly dampens the initiation, intensity, and subsequent spread of fire. After rain, the fuel has sufficient moisture, and the risk of fire is almost zero.

Moisture holding capacity depends on weight. Due to the small particle size (the needle has significantly smaller dimensions compared to the leaves), the coniferous litter creates a well-compacted (higher weight per unit area) and a non-aerated litter, which retains moisture well. The litter of conifers, since it can accumulate more than twice the amount of water compared to deciduous litter, has a longer period after rain, when the fuel still has a high moisture content, which prevents fuel initiation and does not support the intensity of fire. Due to the moisture content, it requires a longer drying time under normal natural conditions, is difficult to ignite and does not support the spread of fire. Deciduous litter can in turn accumulate less water and creates a well-aerated litter that dries faster due to air access. Thus, after rain, the deciduous litter, due to the lower moisture content, dries under normal natural conditions, in a significantly shorter time, and thus the risk of fire increases faster, and the litter increases the intensity of the fire. Pine litter (representative of coniferous stands) therefore has a significantly lower risk of fire initiation and development in periods of higher air humidity. Oak and beech litter (representatives of deciduous stands) have a higher risk of fire initiation and development in periods with higher air humidity.

The values of the heat flux required for the ignition of the litter did not differ significantly when comparing the individual stands. Fig. 2 shows the ignition times (s) as a function of the magnitude of the thermal radiation (kW / m^2). A value of ignition time of 0 s in the Fig 2. means that the sample did not ignite.

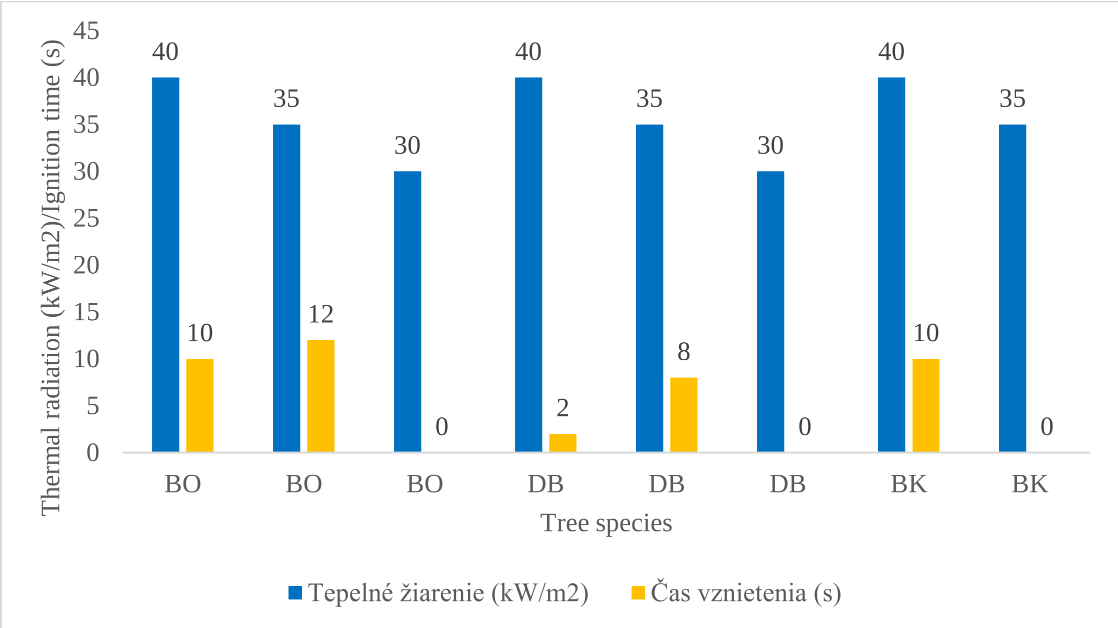

Fig 2. Ignition times of individual stands litter depending on the thermal radiation magnitude

The limit value of thermal radiation required for ignition of pine and oak litter is 35 kW / m^2. At a thermal radiation value of 30 kW / m^2, the litter of oak and pine did not ignite. The limit value of thermal radiation required for ignition of beech litter is slightly higher, namely 40 kW / m^2. At a thermal radiation value of 35 kW / m^2, the beech litter did not ignite. At a thermal radiation value of 40 kW / m^2, in the case of pine and beech litter, ignition occurred after 10 s, while in the case of oak litter, ignition occurred in a relatively very short time (2 s). Beech litter, therefore, required greater thermal radiation to ignite. The oak litter ignited in the shortest time again.

Thermal radiation is the energy needed to ignite a fuel. The ignition time depends on the magnitude of the thermal radiation. The greater the thermal radiation, the faster the ignition will occur. In the case of dry fuels (low moisture content - below the moisture limit value), the energy of the initiation source is used to heat the fuel to the ignition temperature and to form gaseous products. The thermal radiation limit value is the minimum value of the energy of the initiation source that is required to ignite the dried fuel. The fuel is moved to a moisture content below the moisture limit value in periods when the air temperature is elevated for a long time (heat, dry in spring and summer). In the case of overdried fuel, approximately the same ignition energy was required, regardless of the type of vegetation. The difference is in the times when the flame burned. Oak litter is composed of leaves that are large. This litter is well aerated with a high content of air (oxidizing agent) and forms a flammable group (oxidizing agent + flammable substance). This affects the initiation and development of the fire. The oak litter ignited after only 2 s, which means that it has a high risk of fire and can be very easily ignited. On the contrary, in the case of beech and pine litter, ignition occurred after 10 s. Beech litter is formed by small leaves (significantly smaller dimensions compared to oak leaves), which create, compared to oak leaves, better compacted and non-aerated litter with lower air content. Pine litter has the smallest particles and creates a well-compacted and non-aerated litter. The litter of pine and beech was therefore more difficult to ignite. The ignition time therefore depends on the particle size.

Fig 3. shows the maximum and average values of the heat release rate, the values of the total heat released, and the ignition time of pine, oak and beech litter when ignited due to thermal radiation of 40 kW / m^2.

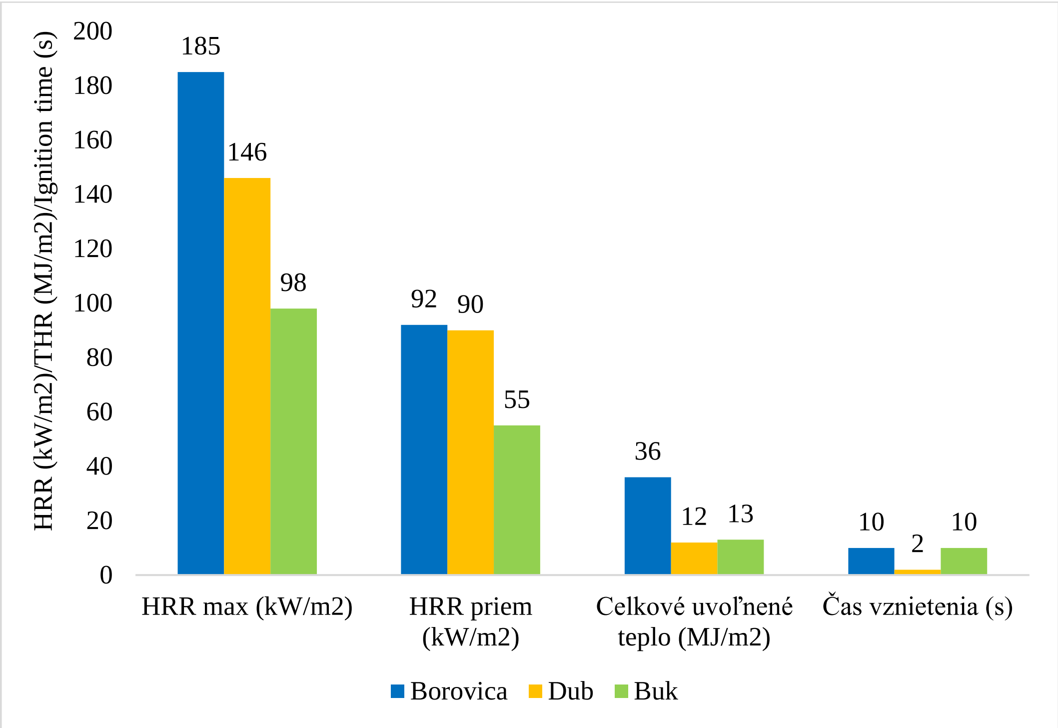

Fig 3. Maximum and average values of the heat release rate (HRR), total heat released (THR) and the ignition time of the litter, when ignition occurred due to thermal radiation of 40 kW / m^2

Pine litter showed significantly higher values of maximum heat release rate (HRR_{max}) and total heat released (*THR*). The HRR_{max} of pine litter reached 185 kW / m^2. This is followed by the HRR_{max} of oak litter (146 kW / m^2). The lowest value of HRR_{max} showed beech litter (98 kW / m^2). The average *HRR* values do not differ significantly by pine (92 kW / m^2) and oak (90 kW / m^2) litter. Lower average *HRR* values showed beech litter (55 kW / m^2). Significantly higher values of THR showed pine litter, up to 36 MJ / m^2, that is three times more than THR of oak litter (12 MJ / m^2) and almost three times more than the THR of beech litter. By pine and beech litter, ignition occurred after 10 s, while in the case of oak litter, ignition occurred in a relatively very short time (2 s).

Fig 4. shows the values of gross calorific value and net calorific value of oak and pine litter.

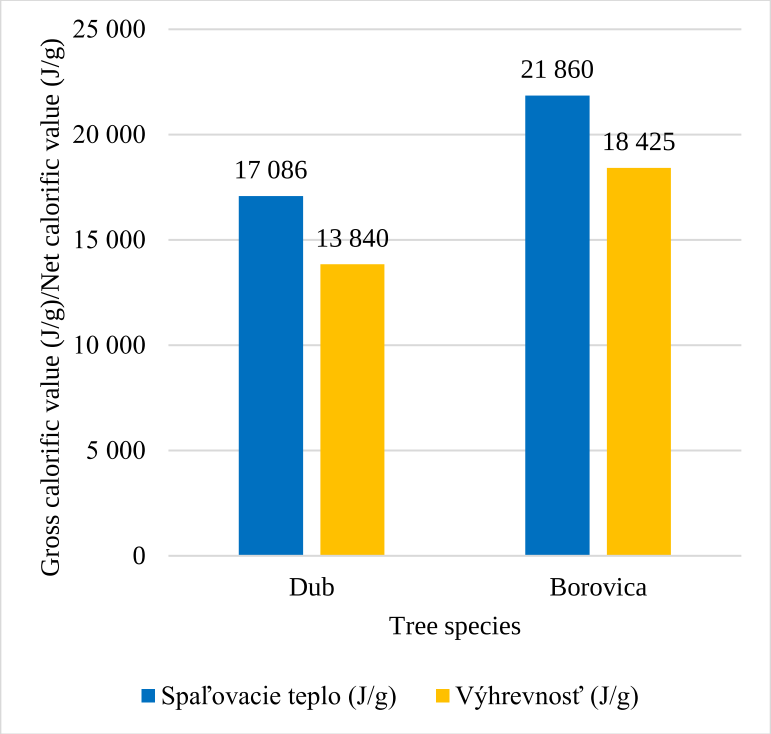

Fig 4. Oak and pine litter gross and net calorific values

The litter of pine had significantly higher values of gross and net calorific value.

Na Fig 5. shows the maximum flame heights and the litter flame burning time of beech, oak, and pine litter.

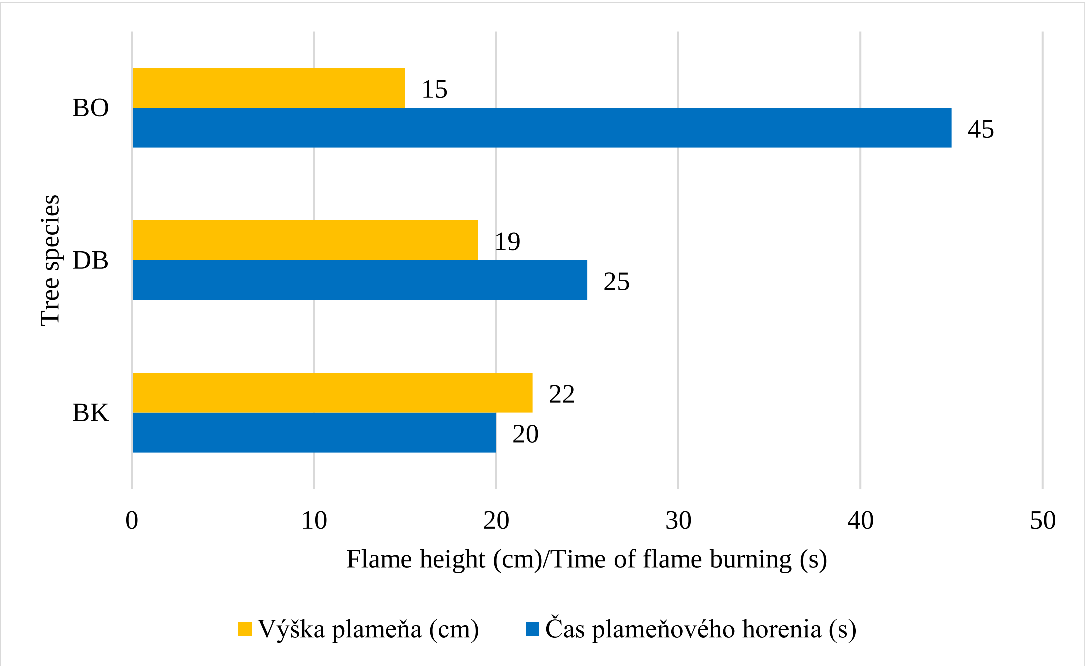

Fig 5. Maximum flame heights and the litter flame burning time

Beech litter showed the shortest time of flame burning (20 s). The oak litter showed the time of flame burning time of 25 s, about 5 s longer compared to the beech litter. Significantly, the longest time of flame burning was recorded by the litter of pine (45 s), the value of which is almost twice if the deciduous stands litter. The beech litter had the highest flame height (22 cm), but this height began to decline rapidly. The litter of the pine showed the lowest flame (15 cm). The litter of the oak had a flame height of 19 cm, but it was able to maintain this height for up to 5 s. The litter of the pine stand produced a consistent flame over time.

The heat release rate (HRR), total heat released (THR), gross and net calorific value have a significant effect on the intensity of fire spread. Pine litter (representative of a coniferous stand) contains many resins and volatile substances (terpenes), which release a large amount of heat during combustion, which further affects the intensity and spread of the fire. The HRR and the THR are expressed in kW / m^2, i.e., energy per unit area. Pine litter forms a well-compacted litter and has a high weight per unit area. Higher values of HRR and THR are caused by chemical composition (resins, volatiles) and higher weight, i.e., the volume of fuel. Gross and net calorific value are expressed in J / g, i.e., energy per unit of weight. By pine litter, higher values of gross and net calorific values are caused by the chemical composition (volatile resin). Pine litter also showed the longest time of flame burning (more than twice as much as deciduous litter), which is also due to the chemical composition. Pine litter therefore poses the greatest risk in terms of fire development and intensity. It creates a consistent flame for a long time with a large amount of heat released. This means that the fire increases in intensity very quickly, dries the surrounding fuels with higher moisture content due to radiant heat and spreads into surroundings.

In view of the ongoing climate change and the growing number of fires in the wildland, it is essential that the system for prognosing, detecting, monitoring, locating, and eliminating wildfires is constantly improved. In the following section, we present measures which application in practice could significantly contribute to improving the situation in the field of prevention of wildfires, as well as minimizing their impact, and thus to reduce the fire consequences.

Early fire detection is key pre-requisite to perform a quick and effective response. The first step should be to cover the areas with a high risk of fire with warning systems that can assess the fire danger and early detect the forming fire. These systems should be equipped with CCTV cameras installed in fire most susceptible areas in locations with good visibility. The recordings from the cameras should real time transmit the videorecords to the control centre, where the operator is sitting, and who is ready to evaluate the recordings optically. Early detection (GPS coordinates) will allow to immediately inform the Fire and Rescue Service operation centre, which will then send forces and resources to fight the wildfire. At the same time, relevant bodies, e.g., forest owners/users/managers are informed. This allows the firefighters to start the fire extinguishing activities in time, prevent its uncontrollable spread and reduce its negative consequences.

The next step should be the effort to prevent mostly the ground fires, which are most common due to the availability of fuel on the ground. The forest owners/users/managers should remove the residues after logging and regularly check the condition and thickness of deforestation at critical locations. When there is a large volume of the litter, they should ensure its removal, accumulation in a designated place, or its controlled burning. They should also remove dead wood and combustible debris.

4 Conclusions

Climate change is current environmental problems. The society is not only finding ways to adapt to these changes, but especially to mitigate them. Due to global warming and rising average annual temperatures, the frequency and duration of periods with higher fire risk are expected to increase, and thus the number, extent and severity of fires will also increase. As the average annual temperature increases, forest fuels will be overdried, which will not only become more prone to ignition, but may also support the fire when spreading. Ground fires belong among the most common fires in the wildland, due to availability, moisture content and volume of fuel.

From the point of view of the future prediction of periods with high risk of fires and the detection of fires, it is important to know the key fuel parameters that affect the fire behaviour. The aim of this study was to identify and compare the parameters of litter of selected tree species, which have a major impact on the forest fire behaviour, especially on its initiation, propagation and further spreading.

The results of the study point to the following important facts.

The more water the litter contains, the more difficult it is to ignite, because the initiating energy is first consumed to heat and evaporate the water, and only then to heat the fuel to the ignition temperature and to form gaseous products. Thus, with a higher moisture content of the fuel, a higher initiation energy is required, and the risk of fire is significantly reduced. In fires that have already occurred, the spread of the fire, in areas with a high-moisture content of fuel, is stopped if the fire does not have sufficient energy to dry out and subsequently initiate the moist fuel. Thus, fuel moisture content significantly dampens the initiation, intensity, and subsequent spread of fire.

Moisture holding capacity depends on weight. Coniferous litter is very difficult to ignite in high humidity conditions and it does not support the spread of fire. Deciduous trees litter is more easily ignited.

When studying overdried fuels, we found that the values of initiation energy required for ignition of coniferous and deciduous stands do not differ significantly. Dried oak litter showed that it should be very easily ignited and therefore was assigned to be of the highest fire danger. The litter of pine and beech was more difficult to ignite, due to the litter structure. Beech litter is formed by small leaves (significantly smaller dimensions compared to oak leaves), which create well-compacted and non-aerated litter, with lower air content. Pine litter is formed by the smallest particles and creates a well-compacted and non-aerated litter.

Pine litter showed also significantly higher values of heat release rate (HRR_{max} of 185 kW / m^2), total heat release (36 kW / m^2), gross (21,860 J / g) and net (18,425 J) calorific value, due to the high content of resins and volatile substances. Pine litter also showed the longest time flame burning (more than twice as much as deciduous litter). Pine litter therefore poses the greatest danger in terms of development and fire intensity.

We also proposed recommendations that could positively affect the future development of safety practices in terms of wildfire prevention and extinguishing.

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Granulometric Analysis of Spruce Wood Dust

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Abstract

The article deals with the determination of the particle size of spruce wood dust and its moisture originating from briquetting and grinding technology. Particle sizes affect the maximum explosion parameters and humidity affects the explosive limits, which create the risk of explosion in production facilities. Humidity was determined according to the methodology STN EN ISO 1666: 2000 Determination of the amount of moisture. Sieves with apertures of 0.5 mm, 0.25 mm, 0.18 mm, 0.15 mm, 0.125 mm, 0.09 mm, 0.075 mm, 0.063 mm, 0.045 mm, 0.4 mm were selected for sieve analysis. 0.032 mm and 0.001 mm. The sieve analysis was performed according to the internal methodical procedure IM-AS 200. The measured moisture values of the spruce wood dust samples taken from the grinding technology reached an mean of 8.42% humidity and the mean humidity determined for the samples from the briquetting press was 7.25%. Samples taken from briquetting show lower moisture than dust from the grinder, this affects the method of processing, briquette pressing is performed at an elevated temperature, which reduces the humidity of the mixture. By evaluating the particle size samples by sieve analysis, we prove that the spruce wood dust taken from grinding has the highest proportion of 46.74% for the fraction from 0.063 to 0.075 mm and for the fraction from the briquetting press the highest proportion of 45.44% in the fraction from 0.106 to 0.125 mm. The results will be used for explosion prevention and protection in potentially explosive atmospheres of the timber industry working with these types of standing equipment.

Keywords: Grinding and briquetting technologies; Norway spruce (*Picea abies [L.] Karst.*); sieve analysis; wood dust

1 Introduction

Wood dusts are among the combustible organic dusts that are capable of an oxidative reaction. In the form of an aerogel (settled dust) in the air they burn with a flame and after agitation with the air in the form of an aerosol (agitated dust) they form an explosive mixture (Balog, 1999; Tureková, Balog, 2004). In wood processing technologies, wood raw material is processed by woodworking machines of various types, such as saws, milling machines, wood lathes, grinders, etc. Woodworking machines differ in their effect of tools on wood, where a semi-finished or finished product and residual wood in the form of sawdust, shavings and dust are formed. The size fraction of residual wood material, which accumulates in layers in plants or is agitated at the source of processing, depends on the type of machine and its tool. An explosion may occur if the minimum concentration, the presence of the initiation source and the space are met (Balog, 1999; Tureková, Balog, 2004).

The properties of combustible dusts are given by fire engineering parameters, which are determined in laboratories and are not physical constants. Combustible dusts do not show the same values of fire technical characteristics, even if they are produced and processed under the same or different conditions in parts of technological equipment (Damec, 1993; Sklenárová, Štroch, 2019). To assess the fire danger, we determine the fire technical characteristics of settled and agitated dust. The fire-technical parameters of wood dust in the settled state include the following determinations: minimum ignition temperature of settled dust t^u_{min} and the respective ignition ignition time τ_i, flame spread rate, combustion heat and calorific value, critical degradation temperature, critical heat flux of radiant heat to ignite the deposited dust and oxygen number (Cashdollar, 2000). In the turbulent state, the fire technical parameters of wood dusts are determined: minimum ignition temperature of turbulent dust t^r_{min} and corresponding induction ignition time τ_i, lower explosion limit (LEL), maximum explosion parameters (maximum explosion pressure p_{max}, maximum increase in explosion pressure $(dp / dt)_{max}$, cubic constant K_{St}), minimum initiation energy MIE and limit oxygen content (LOC) (Cashdollar, 2000). The study of methods for assessing the risk of ignition of dust / air in an explosive environment by electrostatic discharge was discussed by Gabor et al. laser initiation of PETN-based composites (Pentrit) and submicron coal particles has been addressed and investigated by (Gabor at al., 2019; Aduev et al., 2016). The size of the dust particles affects the explosive atmosphere in operation and the brisance of the explosion. Granulometric analyzes are performed to determine the size of the dust particles and to classify them. The comparison of the results confirmed the proportion of granulomertic fractions of sand abrasive wood typically processed in the furniture industry (beech, oak, spruce, fir and alder) (Marková et al., 2016). The study by Očkajová et al. compared the granulometric composition of grinding powders of selected tree species (beech and oak) and determined the statistical significance of individual factors (type of grinder, wood species, grit grain, direction of grinding), which affected the percentage of fractions < = 0.08 mm. The results confirmed that the use of narrow and hand (belt and disc) grinders caused a high percentage of fractions < =0.08 mm, in all cases above 90% (Očkajová et al., 2018). Kučerka and Očkajová present the results of the particle size distribution of heat-treated oak and spruce wood with a focus on the fine and dust fraction. The results showed in the milling of oak that with increasing wood treatment temperature the proportion of dust fraction increased from 0.40% and during grinding the opposite trend was shown, namely a decrease in the proportion of dust with increasing processing temperature (Kučerka, Očkajová, 2019).

The fire performance characteristics include the determination of the minimum initiation energy (MIE). The study tested the initiation of dust explosions by electric discharges of a spark in an explosive dust concentration. Large particles have been found to initiate disintegration at lower voltages than smaller ones (Randeberg, Eckhoff, 2006). Eini et al. collected experimental MIE data from the literature and subsequently created group contribution (GC) models using weighted nonlinear least squares regression. The proposed models provided new tools for computer-aided product design (Eini et al., 2020). New diagnostic capabilities available for dust explosion research in the study were investigated by Schweizer et al. The research was carried out by applying high-speed digital in-line holography (DIH) to volumetric and characterization of dust concentrations near the initiation zone of the device (Schweizer et al., 2020). Pacáková presented in the study statistical evaluations by analysis of variance. The method made it possible to compare the mean values of more than two basic sets. The result was whether a null hypothesis could be accepted at the chosen level of significance (Pacáková, 2009). Bernard et al. explain the Langlie method for determining the parameters (mean energy value E50 and standard deviation σ) of the relevant statistical law. A comparison of normal and lognormal law was achieved and the best agreement was reached with lognormal law (Bernard et al., 2010). Nejtková and Marek mentioned in the article the investigation of two real cases of explosions with subsequent fire. A digital spatial deformation analysis was used to investigate the causes of fires and explosions by the Fire and Rescue Service in the Czech Republic, which was used to examine the scene, subsequent documentation, and digitization of the fire site (Nejtková, Marek, 2019).

Spruce wood dust is created as a residual material in the technology of grinding in woodworking with specific properties. It forms a dispersion system, which is formed by the dispersion of spruce particles in a continuous phase of the dispersing medium. Spruce dust particles with a lower fraction react with air and initiate more brisantly than particles with a higher fraction.

The properties of spruce wood dust determine the fire technical characteristics, which are indicators of the assessment of the risk of fire and explosion. All combustible organic dusts, including spruce wood dust, are heterogeneous materials, which differ significantly in processing in technology, depending on the production machine and the machining tool.

The aim of the study is to statistically evaluate the moisture and size of spruce dust particles from the influence of the type of machinery in the technology. Samples of spruce wood dust were taken from two types of machinery - a grinder and a briquette press in a woodworking plant.

2 Material and Methods

Norway spruce (*Picea abies [L.] Karst*.) is a coniferous tree and is one of our most important commercial trees, both in terms of the production of quality wood, but also in terms of representation in our forests. At present, its representation is around 22%. Spruce wood has excellent mechanical properties and has the most versatile use of our main commercial woods, it is suitable for mechanical processing in the woodworking industry (lumber production), but also for chemical processing - cellulose production (lower quality wood). The wood is coreless with white and mature wood, it is light in color with a yellowish tinge (Zubček, 2019). Norway spruce (*Picea abies [L.] Karst.*) belongs to the mature woody trees (Sarvaš et al., 2015; Račko et al., 2018).

Processing in the woodworking industry often involves, among other things, sanding wood surfaces for proper handling and final product design. The input raw material for briquetting is wood sawdust and dust, which are transported to the line by a screw conveyor from the hopper. They are further divided into individual briquetting presses, which are arranged in sequence. In presses, sawdust and dust are pressed into the shape of briquettes (Mračková, Palugová, 2019).

Sampling of spruce dust from the technology of wood sanding and briquetting

Spruce dust samples were taken from the technology of sanding wood and pressing briquettes directly from the source. Sampling was performed several times according to the following procedure:

1. Switch off the extraction of wood residues so that the residues formed after processing the spruce wood settle in the form of an aerogel.
2. After the dust has settled, proceed with a collecting tool (shovel) and collect the accumulated spruce dust residues from the machine directly at the place of origin.
3. Pour the collected material for the experiment into closable crates so that the percentage of moisture removed does not change.
4. This procedure is performed several times in succession, up to the amount needed for experiments and research.

For granulometric analysis, we collected 200 g of spruce wood dust, which was subjected to moisture determination before analysis.

2.1 Determination of moisture and sieve analysis of spruce wood dust

A Mettler Toledo HS153 moisture analyzer was used to determine the moisture content of the tested spruce wood dust and the evaluation was performed in accordance with the methodology STN EN ISO 1666: 2000 Starch. Determination of the amount of moisture (STN EN ISO 1666: 2000). AS 200 series analytical screening machines are used in the fields of research and development, for particle size analysis. All screening machines of the AS 200 model series work on the principle of electromagnetic drive.

The sieve analysis was performed according to the Internal Methodological Procedure IM-AS 200 entitled: ,,Methodology for determining the grain size of loose wood on the AS 200 sieving machine". Sieve analysis was performed with samples weighing m = 50 g, for a sieving time τ = 15 min on a set of sieves with mesh gaps: 0.5 mm, 0.25 mm, 0.18 mm, 0.15 mm, 0.125 mm, 0.09 mm, 0.075 mm, 0.063 mm, 0.045 mm, 0.4 mm, 0.032 mm and 0.001 mm. The weights of the fractions on the sieves are determined on laboratory scales with a weighing accuracy of 0.01 g.

2.2 Statistical evaluation of explosion experiments of spruce wood dust

As part of the statistical evaluation of data, in addition to the methods of descriptive statistics, we used a two-sample Student´s t-test to verify the statistical significance of the difference in mean moisture of spruce dust particles from two types of technologies - briquetting and grinding.

To approximate the probability distribution of test statistics, we used Student´s t-distribution, which is recommended for small selection ranges ($n < 20$). The tabular and graphical tools MS Excel 2016 was used for statistical evaluation of the data. We used the statistical software STATISTICA 12 to test the hypothesis of equality of mean humidity.

3 Results and Discussion

In the results, we present two types of technologies, from which samples of spruce dust particles come from briquetting and grinding.

3.1 Statistical evaluation of experimental results of spruce wood dust moisture

The results of humidity testing are presented in Tab. 1. Based on the p-value (0.006) corresponding to the result of the t-test, we state that there is a significant difference in the mean humidity of spruce wood dust originating from the two types of technology. Dust from the grinder has a higher humidity than dust from briquetting technology.

Tab 1. Results of a two-sample Student´s t-test

Variable	Briquetting n = 5, Grinding n = 5								
	Mean (Briquetting)	**Mean (Grinding)**	**St. dev. (Briquetting)**	**St. dev. (Grinding)**	***F*-test**	***p*-value**	***t***	***df***	***p*-value**
Moisture (%)	7,25	8,42	0,54	0,45	1,42	0,741	-3,73	8	**0,006**

In Fig. 1, we observe box plots that represent 95% confidence intervals for the mean moisture value of dust particles originating from the two types of technology monitored. The sample moisture content of spruce dust for the briquette source type was 7.25% and for the grinder type 8.42%. The mean moisture of the briquetting dust particles with 95% confidence is in the range from 6.58% to 7.92%. For the moisture of the grinding dust particles, the lower limit of the 95% confidence interval was calculated to be 7.86% and the upper limit to 8.98%.

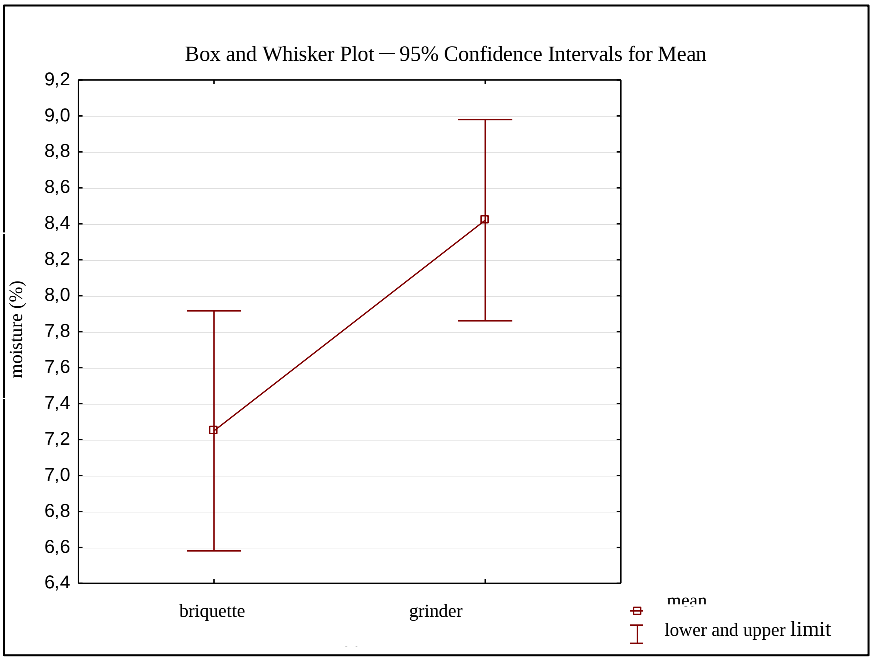

Fig 1. 95% confidence intervals for mean moisture values presented by a box graph of spruce wood dust

3.2 Statistical evaluation of experimental results of sieve analysis of spruce wood dust

The results of the sieve analysis of spruce wood dust are presented in Tab. 2 by means of the mean values for three experimental measurements. The content of the sieve representing the amount of trapped dust particles is given in absolute units (g) and relative.

Tab. 2 Weights and percentages of spruce dust particles from the briquetting press and grinder collected in individual sieves.

Sieves with the size of holes (mm)	briquette (g)	briquette (%)	grinder (g)	grinder (%)
0.500	0.00	0.00	0.00	0.00
0.250	4.47	8.93	1.60	3.20
0.180	8.05	16.09	2.79	5.59
0.150	5.33	10.67	1.84	3.69
0.125	2.09	4.19	3.77	7.53
0.106	22.72	45.44	3.10	6.19
0.090	3.08	6.16	3.49	6.99
0.075	3.91	7.82	3.36	6.72
0.063	0.06	0.13	23.37	46.74
0.045	0.10	0.21	4.49	8.99
0.040	0.08	0.16	1.61	3.22
0.032	0.06	0.12	0.48	0.95
0.001	0.04	0.09	0.10	0.19

The relative abundances from the table are graphically presented by means of a bar diagram in Fig. 2. The highest percentage of spruce dust particles from the grinder, which represents 46.74%, is observed with a fraction of 0.075 to 0.063 mm and from the briquette press with a value of 45.44% for the fraction with a particle size of 0.125 to 0.106 mm.

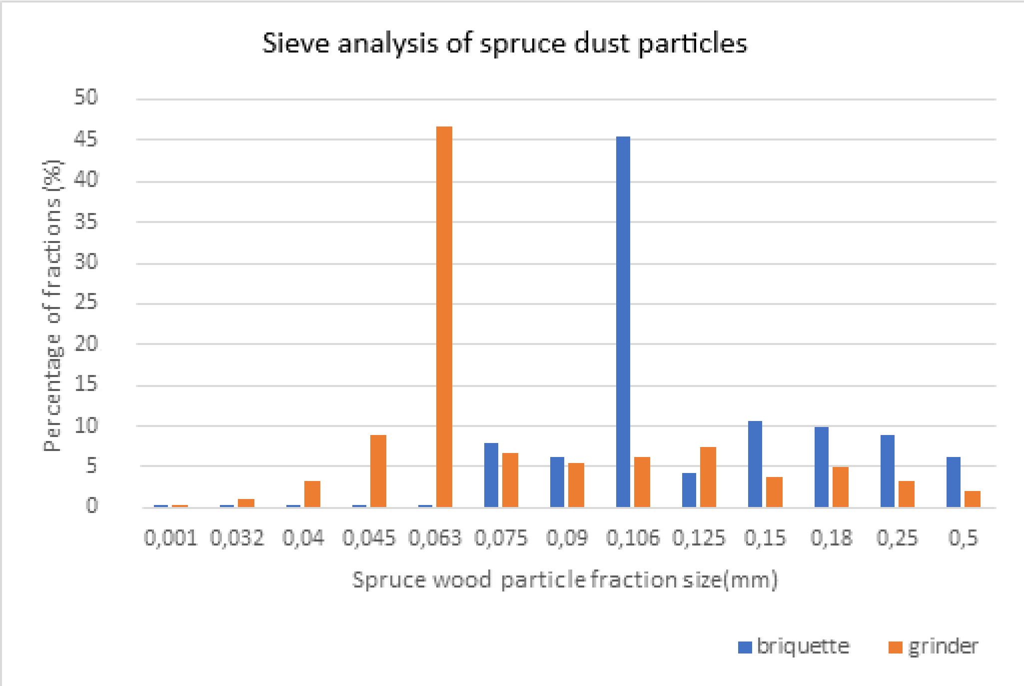

Fig. 2 Graphical representation of particle sizes of spruce dust particles from a briquetting press and grinder with their percentage

In figure 3, we observe a polygon of cumulative masses expressed in percent, by means of which we demonstrate the gradual fall of spruce dust particles through the system of used sieves.

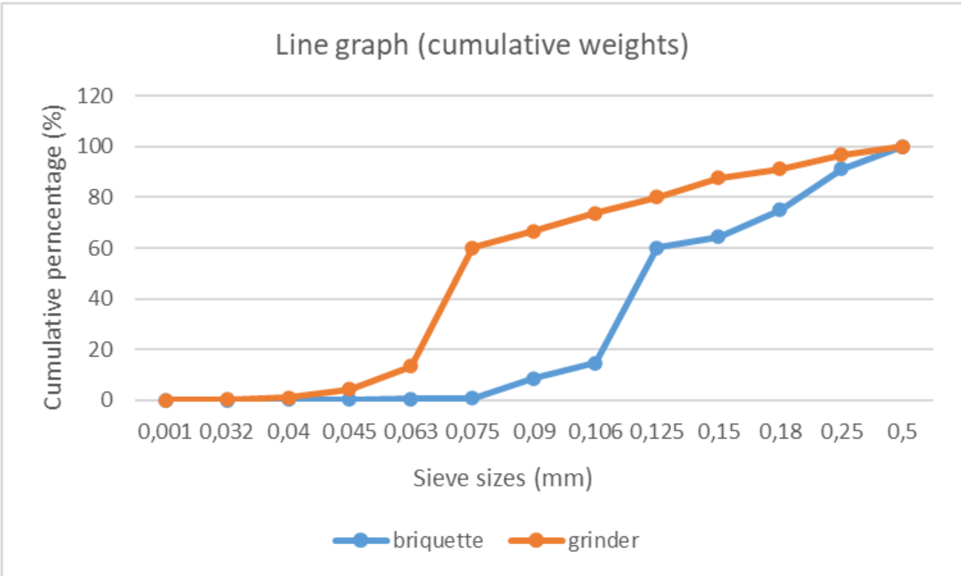

Fig. 3 Cumulative weights of forged spruce dust particles for two types of technology used - briquetting press and grinder.

4 Conclusions

Statistical analysis of data obtained from samples of spruce wood dust originating from two types of technologies - briquetting and grinding, determined the following monitored effects:

- the dry explosive mixture has the greatest range of explosiveness. With dusts with increasing moisture content, the explosive range narrows and at 20% humidity, the dust is almost non-explosive. From the experimentally determined results of spruce dust particles taken from briquetting and grinding technology, we confirmed a statistically significant difference in humidity. Both dispersion mixtures have a humidity well below 20%, we can say that they are flammable and create an explosive atmosphere after agitation.

- from a production point of view, the grinding of spruce wood material results in a high concentration of the dispersion mixture, which could reach the value of the lower explosion limit; According to the National Council of the Slovak Republic no. 393/2006 Coll. On minimum requirements for ensuring safety and health protection at work in an explosive environment, built-in suction device.

- during briquetting, wood sawdust and dust are transported to the line by a screw conveyor from the hopper and further divided into briquetting presses. The concentration of dust in the air is low, due to the feedstock, which has a higher particle size.

- the results will be used for explosion prevention and protection in potentially explosive atmospheres in the woodworking industry in grinding and briquetting technologies.

Acknowledgments

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Effect of Selected Meteorological Factors on Forest Litter Moisture Content and Fire Danger Degree

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Abstract

The aim of the study was to prove the effect of selected meteorological factors on the moisture content of forest litter and the degree of fire danger. The measurements were provided by the calibration of a measuring device for measuring the moisture content of Norway spruce litter. Field measurements were performed in surroundings of Zvolen, in the Scots pine (*Pinus sylvestris*), European beech (*Fagus sylvatica*) and Norway spruce (*Picea abies)* stands, at the edge of the forest stand. In the period from April 1 to September 30, 2020, there were measured and analyzed the following meteorological factors: air temperature, total precipitations, and relative air humidity. The measured factor values were the subject of the analyses to determine the relation between the course of studied meteorological factors and the degree of fire danger. The historical fires, which occurred in the territory were studied and compared with the days of high and very high fire danger degree. The meteorological factors correlation coefficients significance evaluation results, in relation to the moisture content of forest litter at the stand edges and in the stand interior, showed that there is very important relationship between the air temperature, the relative air humidity, the fire danger index and the fire danger degree of the forest litter, especially at the edge of the stand. When comparing the interior of the stands of Scots pine, European beech, and Norway spruce, the most significantly are manifested the meteorological factors right in the spruce stand. The interior of the Scots pine and European beech stand is not so significant in relation to the moisture content of the litter, except for the index of fire danger, which appears to be an important characteristic for the degree of fire danger. The study also showed that different microclimate at the edge of the stand, as well as different microclimatic conditions inside the stands form conditions for different degrees of fire danger in those stands.

Keywords: European beech litter; Scots pine litter; Norway spruce litter; forest fire; litter moisture content.

1 Introduction

The first preserved mentions of forest fires date back to the period around 1,200 A.C. A forest fire can be defined as a sudden partially or completely uncontrollable emergency, which is limited in space and time. Forest fire has a negative impact on all social functions of the forest. It is one of the most dangerous harmful factors which destroys forests in Slovakia every year. Except for the effects of atmospheric energy or persistent dry warm weather, fires are also caused by irresponsible human behaviour. The most common manifestations of irresponsible behaviour include handling open flames in places where it can spread uncontrollably, smoking, and burning shrubs and herbs in the spring. If forest fires are supported by wind and a suitable meteorological situation, they can affect a large area in a relatively short time. The fire weather conditions studies are known mainly from the region of southern

Europe (areas near the Mediterranean Sea) but also from Australia and North America, where it forms long-term fires. (Krakovský, 2004, Osvald, 2005, Stolina el al., 2000).

The aim of the study was realisation of an experiment focused on the effect of meteorological factors on the forest tree litter and the danger of forest fires in the surroundings of Zvolen town, especially in selected stands of Scots pine, Norway spruce and European beech. The experimental part also included measuring and analysis of the trend of air temperature, total precipitations, and relative air humidity during the fire season, i. e. in period April 1, 2020 - September 30, 2020.

2 Material and Methods

The experimental part was carried out in the summer of 2020 in the surroundings of the Zvolen town, in a special-purpose facility of the Technical University in Zvolen – Arboretum Borová Hora. Moisture content of fine fuel and forest litter was measured in three forest stands. These were forest stands of Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) and European beech (*Fagus sylvatica*) located in the altitude range of 315 to 330 m above sea level.

The measurement of spruce litter was realised, first by the calibration of the measuring device (Fig. 1 - left) used for measuring the moisture content, i. e. Moisture Meter Wiltronics ME 2000, as the measuring device already contained calibrations of other mentioned forest litters.

Fig. 1 Calibration process in the laboratory (left), field measurements of litter moisture content in the Arboretum Borova Hora (right)

When calibrating the measuring device, there were followed the steps of the verified methodological procedure, which is introduce in the work of Korísteková, (2018). At the beginning of the calibration itself, it was necessary to obtain spruce litter, which was collected on the areas of the Arboretum Borova hora. From the obtained organic material (spruce litter) we prepared samples weighing 10 g, which we dried at constant temperature of 105 ° C for 24 hrs. to obtain an absolute dry material. After 24 hrs, the dried samples were placed in polyethylene film bags fitted with a sealing cap. A known volume of water was added to the samples in the bags, which represented the expected moisture content of the sample. The wetted samples in the bags were reinserted into other identical bags to minimize moisture content loss from the prepared samples. All samples prepared and moistened in this way were again placed in a hot-air oven and were dried at a temperature of 55 ° C for 24 hrs, to achieve stabilization of the moisture content in the prepared samples. After 24 hrs, the samples were repeatedly weighed to determine moisture content loss. Using a Moisture Meter Wiltronics ME 2000, the final moisture content value was determined and measured 3 times to achieve higher accuracy. The last step was to calculate the calibration curves.

After the calibration of the measuring device was completed, the moisture content measurements of the forest litter in the areas of the Arboretum Borova hora Arboretum were done (Fig. 1 - right). All field measurements were performed in already mentioned three forest stands (pine, spruce, and beech) in two parts for each stand, i. e. for the stand edge and for the stand interior. Measurements performed in selected days in the period from August 7, 2020, to September 4, 2020, were performed from c.a.

01.00 PM to 02.00 PM. As part of field measurements, air temperature, air flow rate, dew point and air humidity were also measured with a portable TestoTerm. At each of the 6 measuring stations, i. (stand interior and stand edge) a fixed measuring device Minikin i-line RTHi was also installed. Monitoring of other meteorological factors was provided by an automatic meteorological station EMS Brno, located at the station Arboretum Borova hora. The calculations of the fire danger index/ degree in accordance with the methodology of Škvarenina et al. (2004) were provided, using the EMS Brno software and the database of meteorological measurements of the Department of Natural Environment of the Technical University in Zvolen.

3 Results and Discussion

The course of the weather situation during the fire season, i. e. since April 1, 2020 to September 30, 2020, was expressed by the course of air temperature, precipitations, and relative air humidity. The graphical representation is introduced in Fig. 2 and 3.

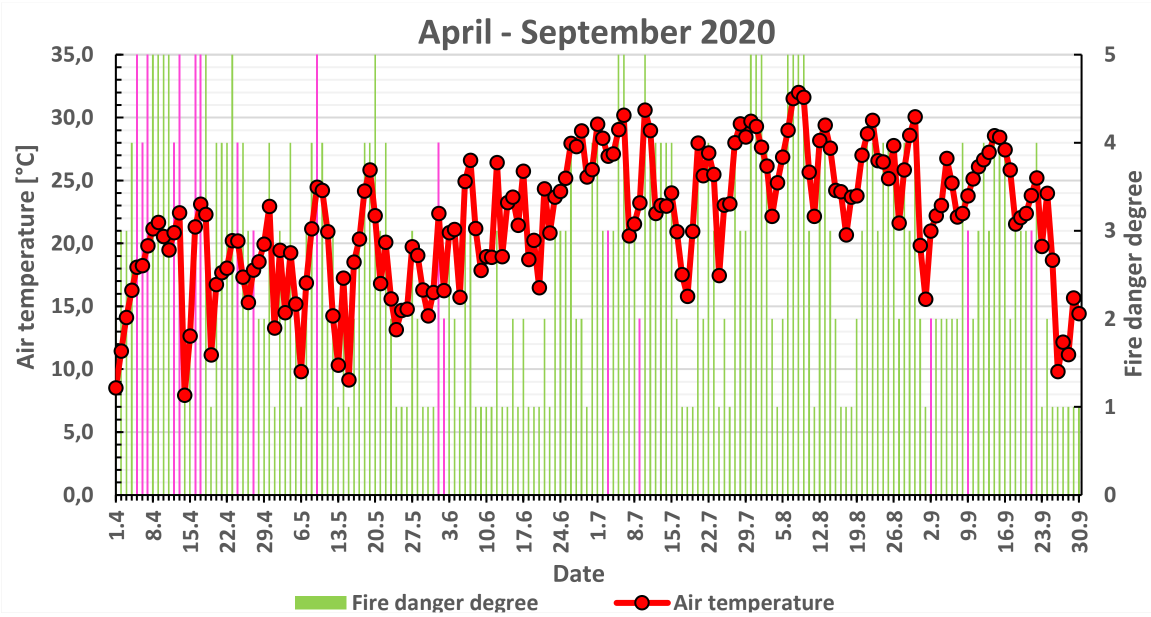


Fig. 2 Course of air temperature and fire danger degree in period April 2020 - September 2020 with indicating the days (pink colour) with wildfire occurrence.

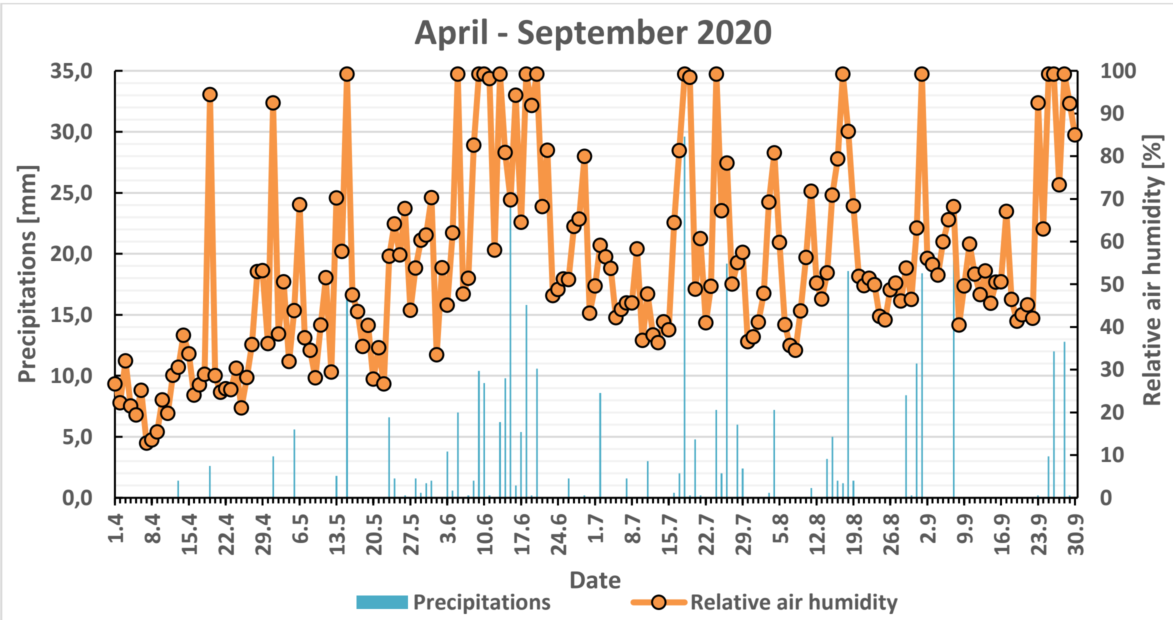


Fig. 3 Course of relative air humidity and precipitations in period April 2020 – September 2020

Analysis of weather course in the monitored period provides the following text. The meteorological parameters which were studied: air temperature, relative air humidity, total atmospheric precipitations and the fire danger which was set based on the fire danger index. Further, we comment in detail on the course of the weather for each month.

In April 2020, the monthly duration of sunshine was strongly above normal, April was extremely sunny. There were up to 29 sunny days in the Zvolen region with a daily duration of sunshine of more than 5 hours. According to the Arboretum Borova hora station data, it was a temperature-normal to slightly above-normal month (with a positive deviation of 0.3 ° C for the Zvolen basin from the long-term average). There was recorded the maximum daily air temperatures on April 8 to 9 2020 and April 17, 2020, when the air temperature rose to 18.1 to 26.9 ° C. April was extremely dry. Precipitation was extremely below normal in the Zvolen region (only 17% of the long-term average). The degree of fire danger was extremely high for the spring month, especially the first two decades of the month. The riskiest fire levels (4 and 5) accounted for 65%, which is the highest of all evaluated months. The high number of degrees 4 and 5 (high and very high fire danger) (Fig. 4), together with the course of the weather in April (Fig. 5), was also demonstrated by the number of fires in the wildland in the Zvolen region, see Tab 1.

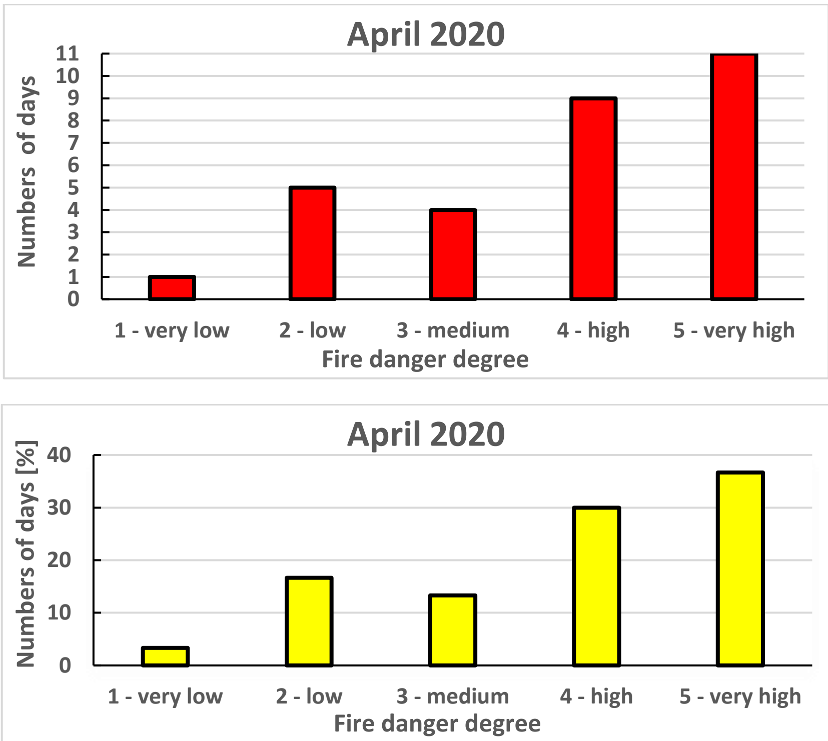
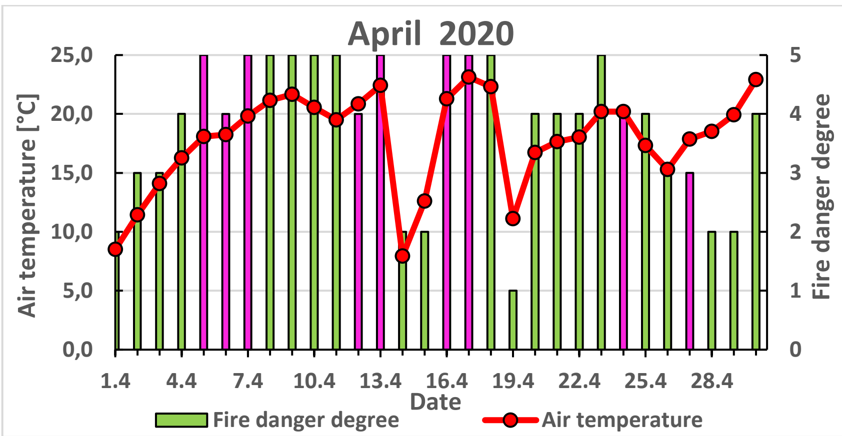


Fig. 4 Bar chart of absolute frequencies of the fire danger degree in April 2020 (top) and bar chart of relative frequencies of the fire danger degree in April 2020 (bottom)



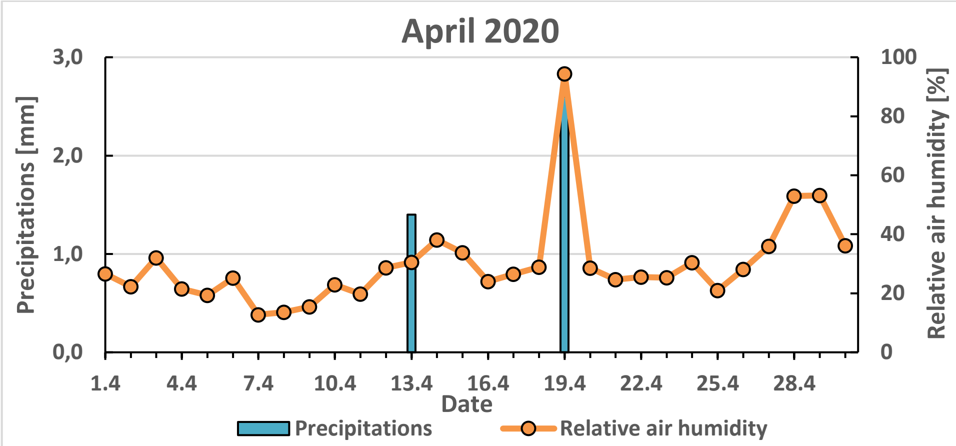


Fig. 5 Course of air temperature and fire danger degree in April 2020 (top) and course of relative air humidity and total precipitations in April 2020 (bottom)

May 2020, the monthly duration of sunshine in the Zvolen region was above normal (252 hours of sunshine). May was below normal in terms of temperature in the region. The average monthly air temperature was of 12.5 ° C, with a negative deviation from the normal of 2.0 ° C. Daily maximum air temperatures ranged from 20.7 to 28 ° C and occurred on May 9 – 11 2020 and on May 19, 2020. During May 2020, there were recorded 5 summer days. Monthly precipitation totals were below normal. The monthly total precipitation was only 45 mm, which represents 58% of normal. There were recorded 3 storms. High values of cloudiness, lower temperatures and evenly distributed precipitation during the month conditioned a relatively favourable state of fire danger, where the low risk of forest fires dominated (first degree - 33%). Highest fire danger degree occurred only in two days in May (May 9, 2020, and May 20, 2020).

June 2020. The duration of sunshine in June was below normal (199 hours of sunshine). The month was slightly above normal in temperature. The average monthly air temperature was of 18.5 ° C, with a positive deviation from the normal of 1.1 ° C. The maximum daily air temperatures did not occur significantly until the end of the month, e. g. June 28, 2020, with air temperature above 30 ° C. The first two decades of the month were significant, with precipitations. Precipitation in June was characterized by frequent local showers and storms. There were 18 precipitation days, 8 of them with a storm (e. g. on June 15, 2020). Overall, June was above normal in terms of precipitation (96 mm, which represents 123% of normal). The fire danger index was extremely favourable, with low levels of fire danger (very low to medium degree) dominating. High fire danger degree occurred only three times at the end of the month, the very high degree did not occur at all.

July 2020. The duration of sunshine was amounted to 281 h of sunlight. July was temperature normal. The average monthly air temperature was of 19.8 ° C, with a deviation of 0.3 ° C from normal. The maximum daily air temperatures ranged from 25.6 to 30.5 ° C and occurred on July 6, July 10 to 11, and July 28, 2020. July rainfall was also relatively intense, with frequent storms. The precipitation total measured at the station was of 95 mm, which is 130 % of the long-term normal. On July 18, 2020, the daily precipitation total reached 30 mm. July 2020 was above normal in terms of precipitation. In terms of the fire danger index, the medium and high degree of fire danger prevailed.

August 2020. The monthly duration of sunshine was strongly above normal (265 h of sunlight, which represents 122 % of normal). In the region, whole August was above normal. The average daily air temperature was of 20.6 ° C. The deviation from normal was positive and of 1.8 ° C. The highest daily temperature occurred on August 8, 2020, when the maximum daily air temperature rose to 33.0 ° C. August precipitation was very variable due to frequent local showers and storms. There was recorded a monthly total of 71 mm (111 % of normal), with the whole month being assessed as above normal in terms of precipitation. An interesting fact was observed that precipitations came to the region in three waves, from August 3 to August 4, 2020, then on August 11 to August 19, 2020, and finally on August 29 to August 31, 2020. In contrast, the periods between these waves were relatively dry (relative air humidity was of c.a. 40%), what caused a local increase in the fire danger index, e.g., on August 6 to

August 9, 2020, there were recorded a series of days with a very high fire danger degree. Overall, in August 2020, the high degree of fire danger dominated.

September 2020. The duration of sunshine in September was strongly above normal (195 h, which is 125 % of normal.) In the region, September should be characterized as an above-average month. The average monthly air temperature was of 15.5 ° C, with a positive deviation from the normal of 1.5 ° C. Daily maximum air temperatures rose to about 30 ° C and occurred on September 14 and September 15, 2020. September was also an above-average month due to precipitations. The monthly precipitation total was of 81 mm, that represents 137 % of normal total. The precipitation was not evenly distributed in September 2020, it fell only in the first and last decade of the month. The fire danger index was the highest in low fire danger degree. In the middle of the month, due to precipitation absence and relatively warm weather, a series of days with the high degree of fire danger occurred (September 8 to September 22, 2020).

The data from the Tab 1. points out present the fact that the occurrence of wildfires is related to the fire risky days determined according to the degree of fire danger. In the monitored period, totally 19 wildfires occurred in the surroundings of the Zvolen town. The majority (16 fires) occurred during fire risky days (days with a medium, high, and very high degree of fire danger). In comparison with the same period in 2018, analysed in the work of Ostrihoň (2019), where from the total of 27 wildfires, 18 fires occurred in fire risky days in terms of the degree of fire danger. From the comparison, we found that the number of wildfires decreased in the monitored period of 2020 to 2018, but nevertheless burned more in fire risky days. The distribution of forest fire risk in principle corresponded to the conditions published in the work of Vida et al. (2012). In percentage terms, wildfires in 2020 represent up to 84% of all wildfires in the region and 66% share of fires that occurred in the same period in 2018. In 2020, more than 58% of wildfires occurred in the most fire risky month, i. e. April.

Tab. 1 Wildfires in the Zvolen region in the period April 1 to September 30, 2020

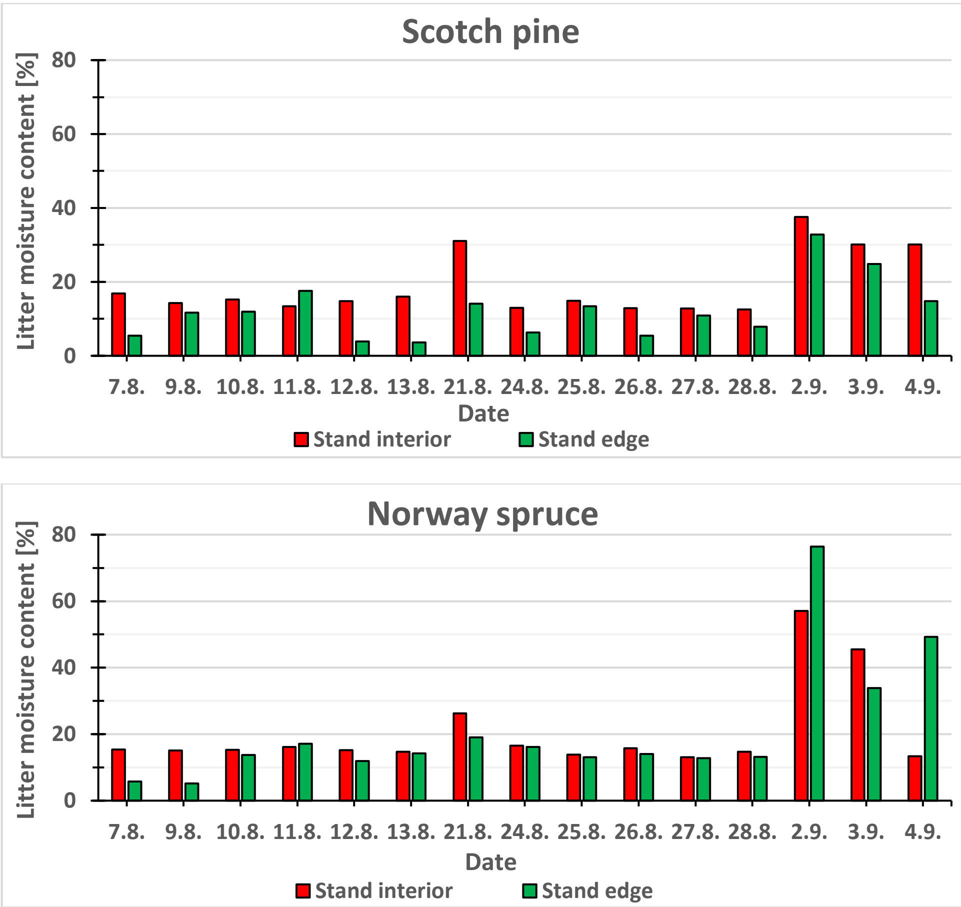
Emergency	Fire site	Fire initiation date	Fire initiation time	Direct damage (EUR)	Case of fire
Grassland fire *	Ostra Luka	05.04. 2020	06.45 PM	100	Smoking
Grassland fire *	Zvolen	06.04. 2020	01.40 PM	20	Smoking
Grassland fire *	Trnie	07.04. 2020	06.00 PM	0	Grass and shrubs burning
Grassland fire *	Ocova	07.04. 2020	11.40 PM	0	Grass and shrubs burning
Mixed-forest fire *	Lukavica	12.04. 2020	04.30 PM	0	Negligence of adults
Grassland fire *	Zvolen	13.04. 2020	11.10 AM	2,000	Electrical short
Grassland fire *	Zvolen	13.04. 2020	12.00 AM	0	Grass and shrubs burning
Grassland fire *	Zvolen	16.04. 2020	02.35 PM	0	Smoking
Wildfire *	Zvolen	17.04. 2020	06.40 AM	0	Setting fire in wildland
Grassland fire *	Sliac	24.04. 2020	05.50 PM	10	Smoking
Grassland fire *	Pliesovce	27.04. 2020	02.20 PM	50	Smoking
Grassland fire *	Zvolen	09.05. 2020	01.25 PM	10	Unknown
Parking area fire *	Zvolen	01.06. 2020	04.20 AM	1,000	Arson
Wildfire	Zvolen	02.06. 2020	02.12 AM	0	Smoking

Emergency	Fire site	Fire initiation date	Fire initiation time	Direct damage (EUR)	Case of fire
Grassland fire *	Zvolen (near railway)	03.07. 2020	07.20 AM	10	Brake system failure
Parking area fire	Zvolen	09.07. 2020	10.15 PM	600	Unknown
Parking area fire	Zvolen	02.09. 2020	03.40 AM	5,000	Arson
Parking area fire *	Zvolen	09.09. 2020	11.18 AM	50	Electrical short
Wildfire *	Zvolen	21.09. 2020	11.35 AM	0	Waste incineration

* Fires occurred in fire risky days (days with a medium, high and very high fire danger degree). Source: PTEÚ MV SR.

During field measurements performed in the Arboretum Borova hora, the course of litter moisture content was monitored. When monitoring the moisture content of the litter (Fig. 6), there was observed in European beech and Norway spruce stands higher moisture content of the litter inside the stand than at the edge of the stand. Exceptions were the measurement in spruce stands on September 2, 2020, and September 4, 2020. A smaller content of moisture in litter was caused by microclimatic conditions in the stand edge. Those allow the water to be evaporated from the litter.

The measurements confirmed the findings reported in some older works, such as Petrík et al. (1986). The warmest and driest microclimate showed the pine forest stand. Petrík et al. (1986) referred to this type of microclimate as the microclimate of sunny coniferous stands. Norway spruce stands were classified into the type of microclimate of shady coniferous stands. The beech stand, on the other hand, represented a type of microclimate of shady deciduous stands.



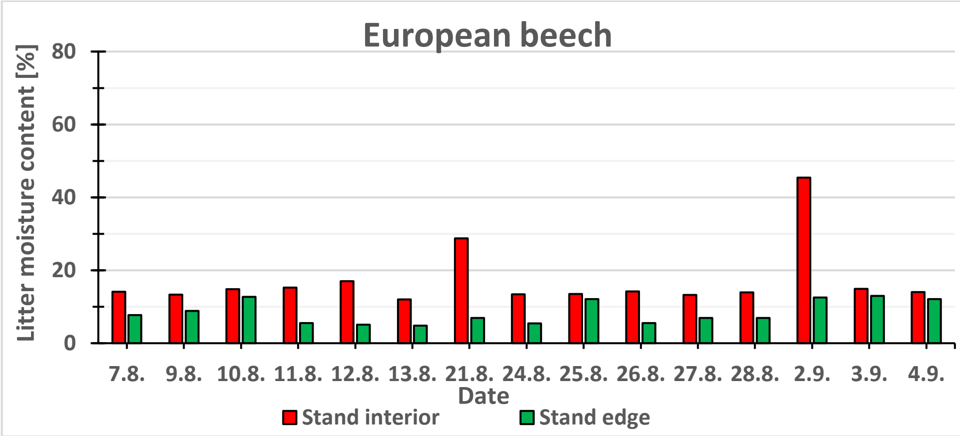


Fig. 6 Comparison of litter moisture content course for pine, spruce and beech in the period August 7, 2020 – September 4, 2020, at the edge and inside the stand

Based on the analysis of the effect of selected meteorological factors on the moisture content of forest litter, we considered, according to Tab 2., the air temperature together with the relative air humidity to be very important meteorological factors in relation to the moisture content of the litter at all studied forest types at the edge of the stand.

Tab. 2 Significance of correlation coefficients of air temperature, relative air humidity, fire danger index and fire danger degree with litter moisture inside and at the edge of the stand

	Scotch pine (*Pinus sylvestris*)		Norway spruce (*Picea abies*)		European beech (*Fagus sylvatica*)	
	Stand edge	Inside stand	Stand edge	Inside stand	Stand edge	Inside stand
AT	***	*	***	***	***	*
RAH	***	n.s.	***	***	***	n.s.
FDI	***	*	***	***	***	*
FDD	***	**	***	**	***	**

Verification of the significance of correlation coefficients between the parameters (AT - air temperature; RAH - relative air humidity; FDI - fire danger index; FDD - fire danger degree) and the moisture content of the studied litter types on the stand edge and inside the stand (significance level: α <0, 1 insignificant ns, 0.1 <α <0.05 * not significant, 0.05 <α <0.01 ** significant, 0.01 <α <0.001 *** very significant, degree of freedom n = 15 (according to Šmelko 1998).

For testing, we used Student's paired test according to Šmelko (1998). The values of the index and the degree of fire danger also showed a very significant relation to the moisture content of the litter at the edge of the stand. Detailed graphical representations concerning the dependence of the monitored parameters on the moisture content of the litter are shown in figures 7 to 12. Correlation analysis of the dependence of the litter moisture content showed its statistically high significance to all monitored meteorological factors and subsequently also to the values of the fire danger degree and fire danger index. This dependence was most pronounced on the stand edges of all three monitored forest types. When monitoring this dependence inside the stands, a significant dependence of the moisture content of the litter on the monitored factors was found only in spruce stand. We assume that this is the result of a specific microclimate of the spruce stand. Spruce stand generally has a high retention (interception) for rainfall, while even during mild and medium rainfall the interior of spruce stands remains relatively dry, because through the dense and multi-layered crowns of spruce stands to the ground falls only a small volume of water from precipitation compared to land not covered with forest. Holko et al. (2009), Oreňák et al. (2010), for middle to lower-lying cultural spruce stands state that spruce crowns retain between 20 and 60 % of precipitation. This fact was also reflected in our results. In contrast, the pine stand, and partly also beech stand, retains significantly less rainwater in the crowns. According to Petrík et al., (1956), the interception of Scots pine is about 28 %, and according to Minďáš et al. (2001), beech stand interception is about 19 – 20 % of the total precipitation in the open area. There is lighter in the pine and partly beech stands, and a more numerous undergrowth of herbs and grasses grows under their crowns, which causes a higher inhomogeneity of the litter moisture content, which is reflected in the higher variability of the results of our litter moisture content measurements.

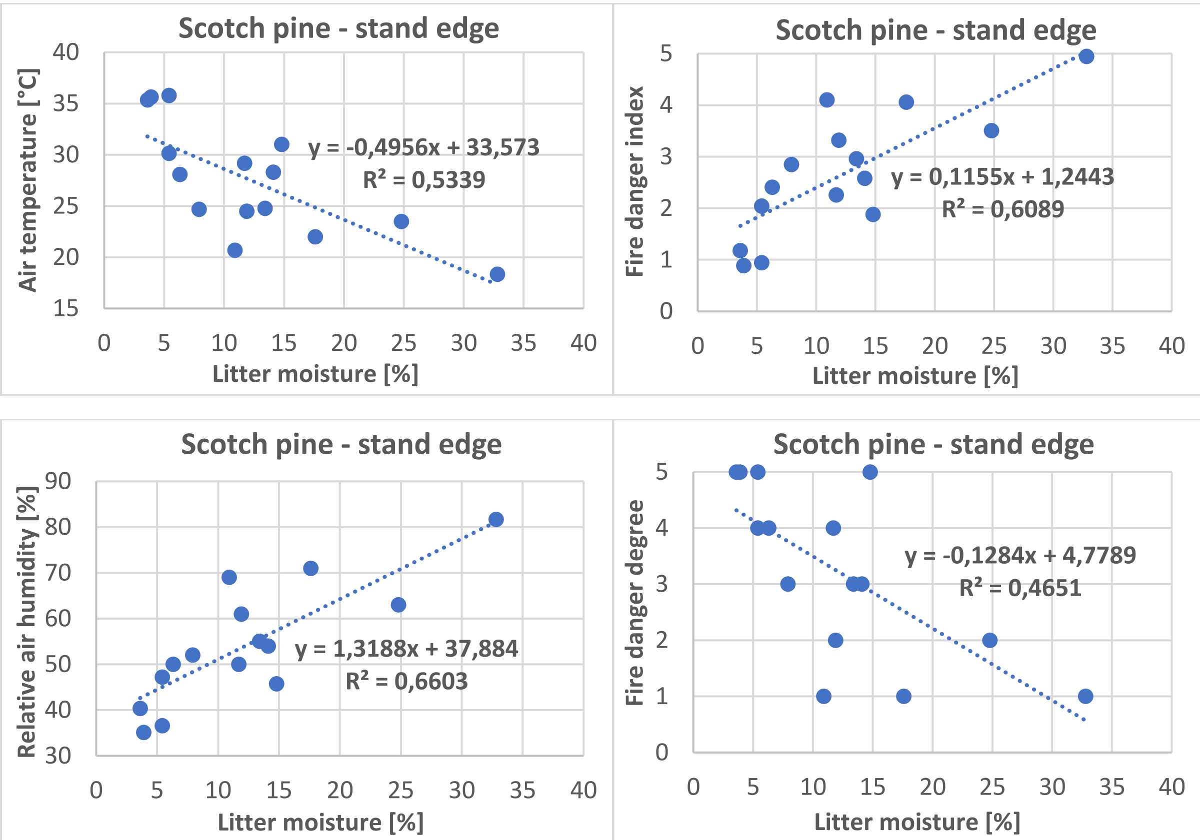


Fig. 7 Dependence of forest pine litter moisture content at the edge of the stand on air temperature (top left), relative air humidity (bottom left), fire danger index (top right) and fire danger degree (bottom right)

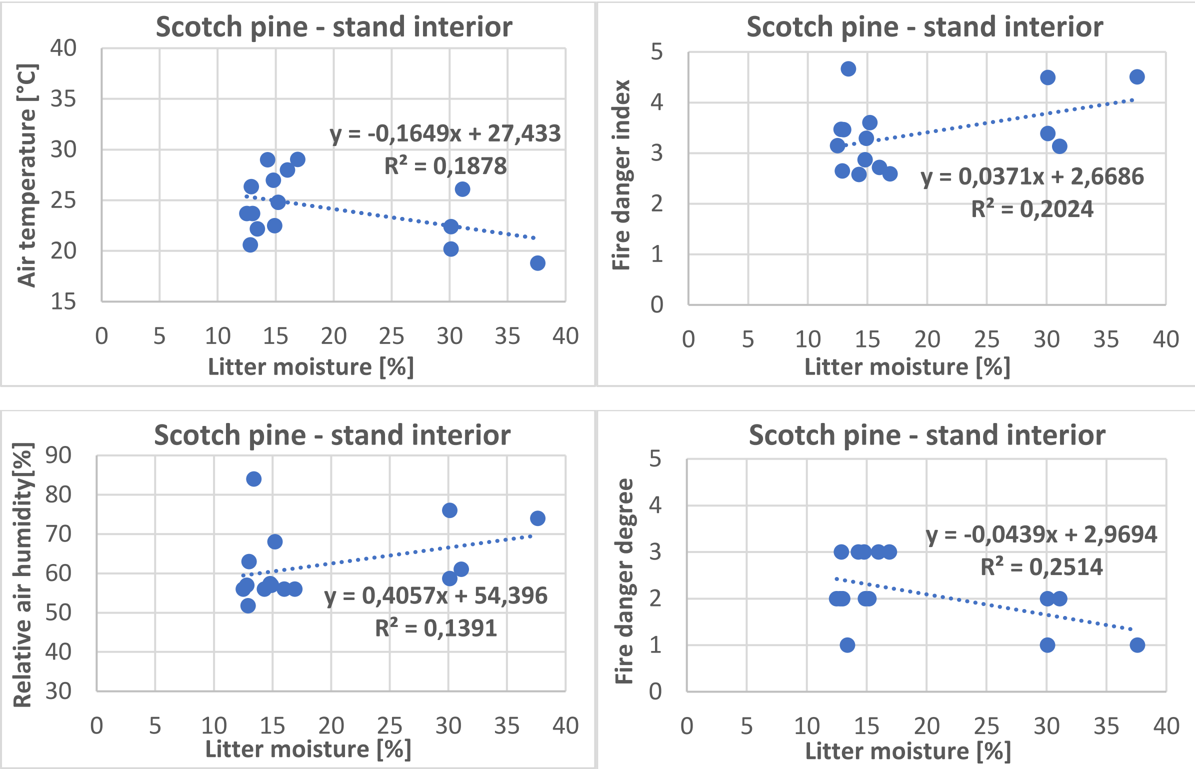


Fig. 8 Dependence of forest pine litter moisture content inside the stand on air temperature (top left), relative air humidity (bottom left), fire danger index (top right) and fire danger degree (bottom right)

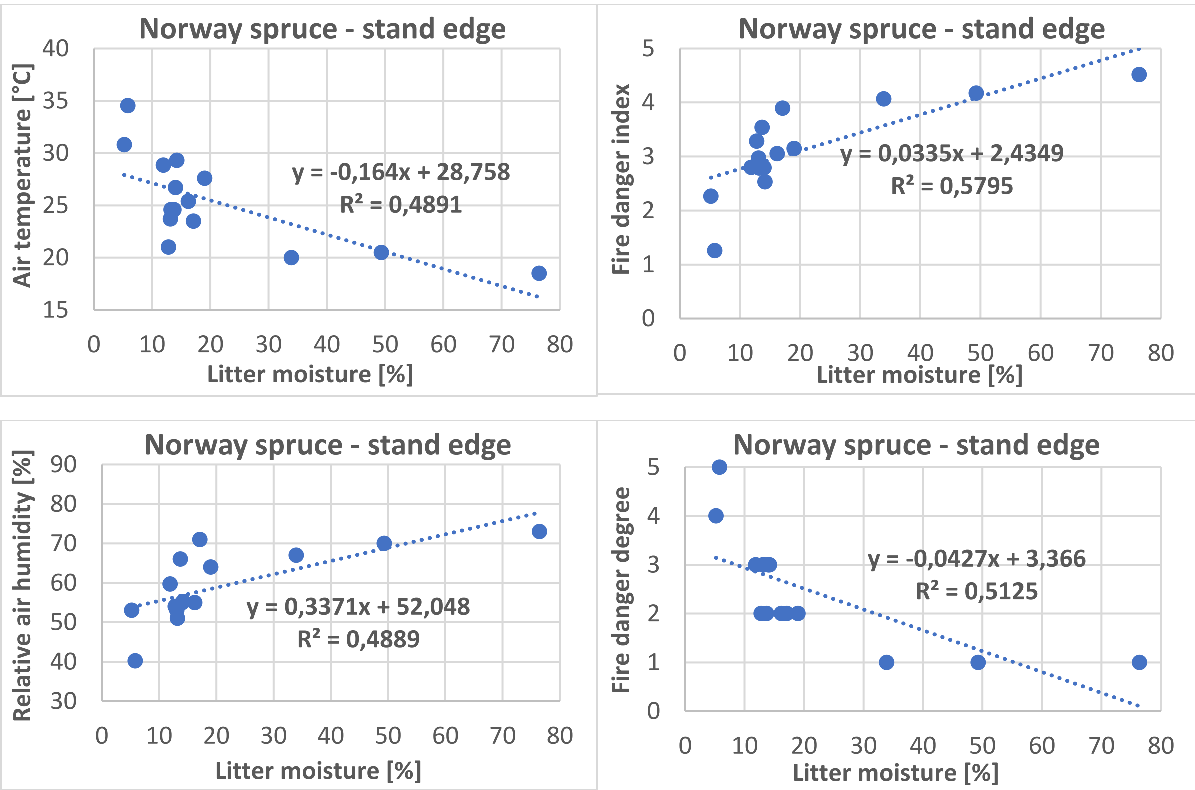


Fig. 9 Dependence of forest spruce litter moisture content at the edge of the stand on air temperature (top left), relative air humidity (bottom left), fire danger index (top right) and fire danger degree (bottom right)

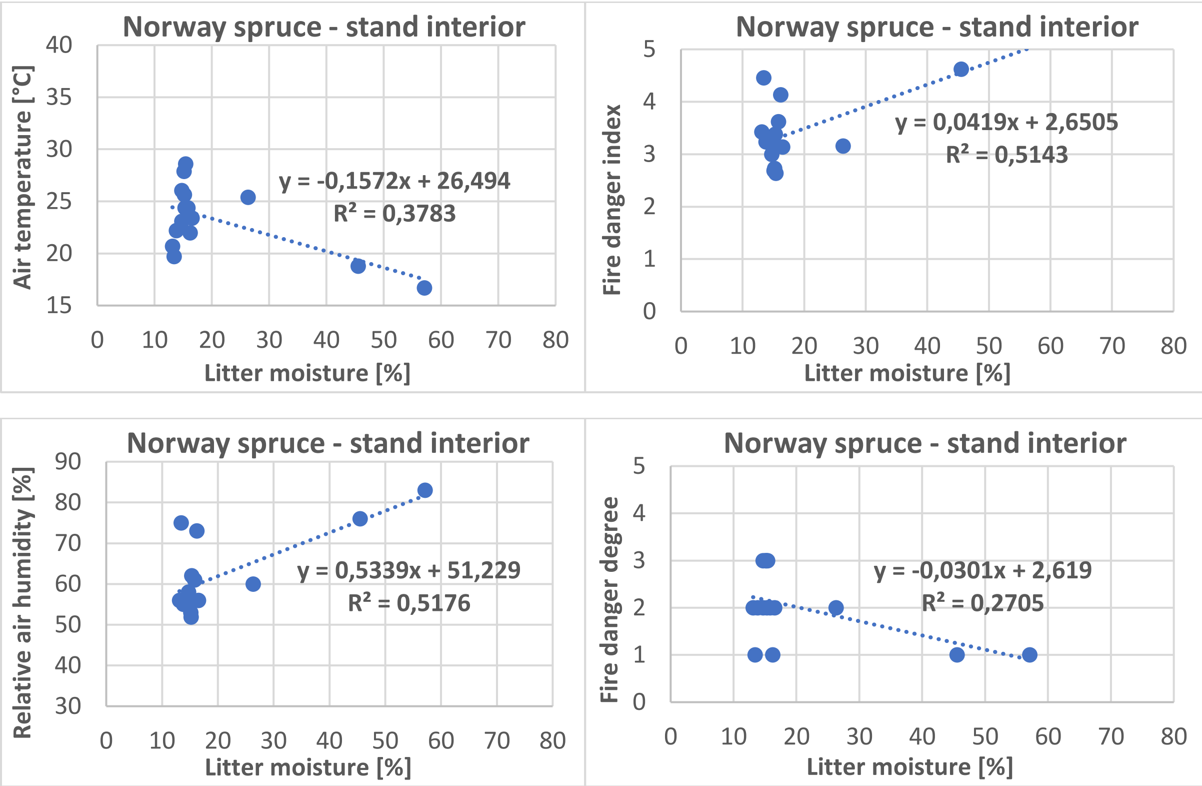


Fig. 10 Dependence of spruce litter moisture content inside the stand on air temperature (top left), relative air humidity (bottom left), fire danger index (top right) and fire danger degree (bottom right)

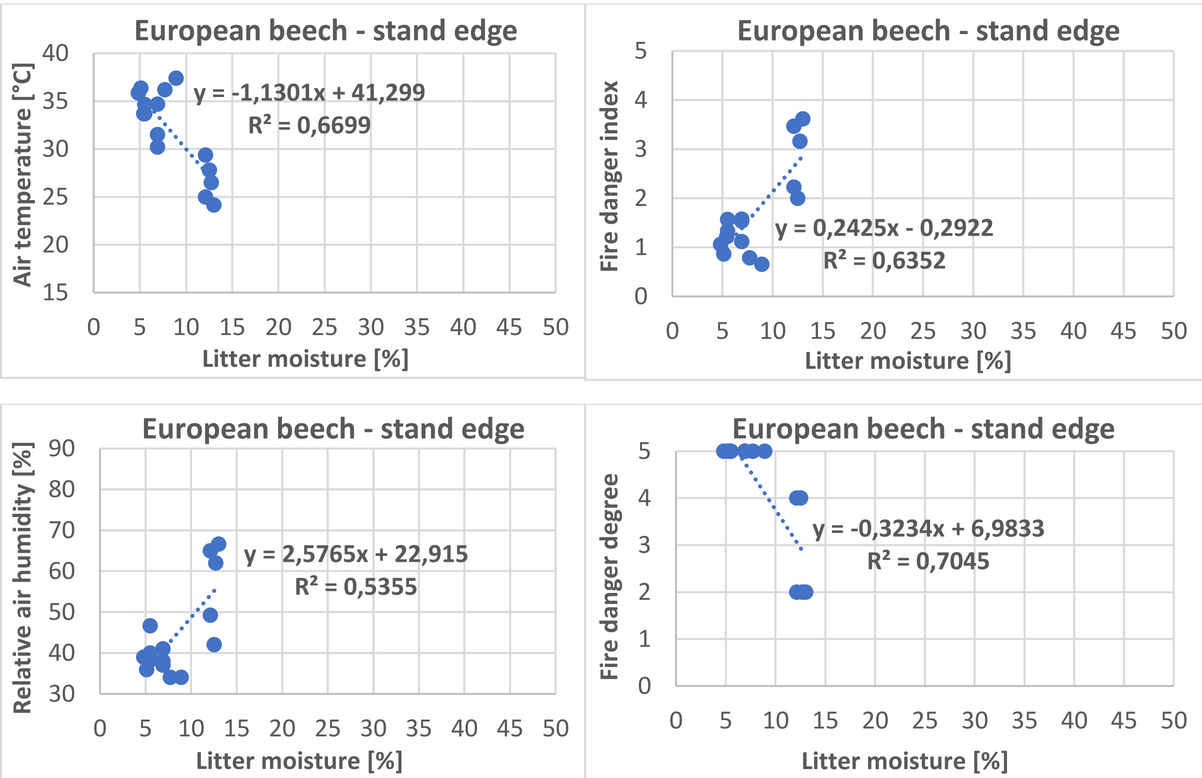


Fig. 11 Dependence of forest beech litter moisture content at the edge of the stand on air temperature (top left), relative air humidity (bottom left), fire danger index (top right) and fire danger degree (bottom right)

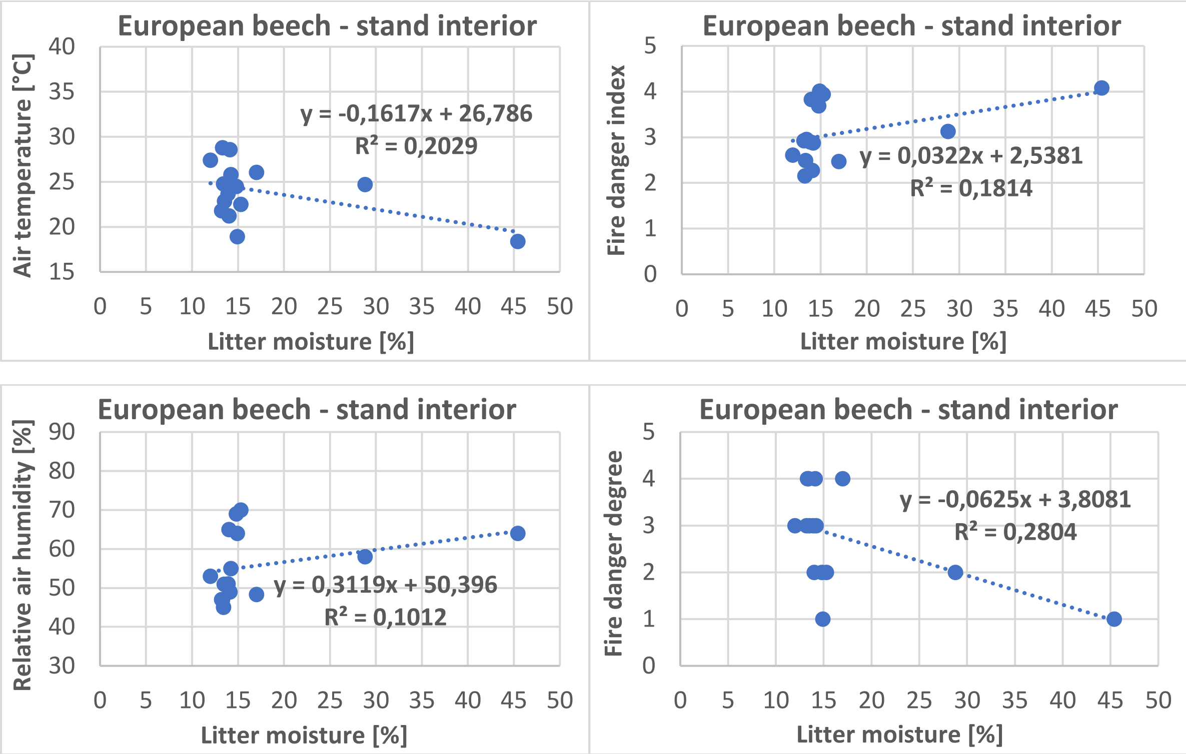


Fig. 12 Dependence of beech litter moisture content inside the stand on air temperature (top left), relative air humidity (bottom left), fire danger index (top right) and fire danger degree (bottom right

4 Conclusions

When analysing the influence of selected meteorological factors on the moisture content of forest litter (Norway spruce, Scotch pine, European beech) and forest fire danger, as well as during detailed study of weather course (especially air temperature, relative air humidity and total atmospheric precipitation) and fire danger in the fire season (April - September 2020), the following facts were found:

- In terms of air temperature, all months, except for May (slightly below normal), were above normal temperatures or at the normal level. In terms of total atmospheric precipitation, the first two months of the fire period (April and May 2020) were significantly below normal, especially April 2020, which was extremely dry. In the next months (June, July, August, and September 2020), the total precipitation ranged from 11 to 37 % above normal. The precipitation in that period was characterized mainly by local showers and summer storms.
- The studied fire season last 183 days, consisting of 43 days with high degree of fire danger (24 %), 42 days with very low degree of fire danger (23 %), 38 days with low degree of fire danger (21 %), 37 days with medium degree fire danger, and up to 23 days with very high degree of fire danger. While, for wildfires, the days with medium to very high fire danger are significant. Compared to the same season in 2018 (Ostrihoň, 2019), when c.a.77 % of fire risky days occurred in August, it was more than half of the days of the first decade with very high fire danger degree in August 2020, when the maximum daily temperature was in the range of 30 - 35 ° C. April 2020 was only slightly above average in temperature. However, it was extremely dry, which was reflected on number fire risky days.
- Field measurements of forest litter moisture content of Scots pine and European beech litter confirmed the fact published by Ostrihoň (2019), where the edge of the stand showed lower moisture content of the litter compared to the interior of the stand. This fact was also confirmed in spruce stand, which, except of two days, showed forest litter with higher moisture content at the edge of the stand than inside the stand.
- When evaluating the significance of the correlation coefficients of meteorological factors (air temperature, relative air humidity), fire danger index and the fire danger degree, in relation to the moisture content of forest litter at the stand edges and in the stand interior, we found that there is

very important relationship between the air temperature, the relative air humidity, the fire danger index and the fire danger degree of the forest litter, especially at the edge of the stand. When comparing the interior of the stands of Scots pine, European beech, and Norway spruce, the most significantly are the above-mentioned meteorological factors manifested right in the spruce stand. The interior of the Scots pine and European beech stand is not so significant in relation to the moisture content of the litter, except for the index of fire danger, which appears to be an important characteristic for the degree of fire danger. These differences are due to the type of forest stand and its ability to differently distribute precipitation, when passing the crowns.

- The study showed that different microclimate at the edge of the stand, as well as different microclimatic conditions inside the stands form conditions for different degrees of fire danger in those stands.

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3D modelling in explosion prevention

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Short report

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Abstract

The study deals with explosion protection in the operation of a production hall for processing wood material, using the CAD visualization of the 3D modelling program SketchUp. The wood operation is focused on the production of children's playgrounds and processes exclusively agate wood. The starting point for the elaboration of a written document on explosion protection was Government Regulation of Slovak Republic no. 393/2006 Coll. on the minimal requirements for ensuring safety and health at work in an explosive atmosphere. Assessment the risk of explosion in the production hall, the classification of areas with explosive atmospheres into zones was modelled in 3D. To minimize the likelihood of explosion and mitigate the impact, devices have been designed to reduce dust in the workplace by means of air-conditioning equipment and air-humidification equipment. The benefits of 3D modelling are supported by Industry 4.0, which in practice means a faster and more efficient display of individual contexts in space. A digital three-dimensional project of an object exported in 3D format (.skp) is an important part of creating a virtual model of explosion protection.

Keywords: explosion prevention; SketchUp; wood processing; 3D modelling

1 Introduction

The job of an engineer in security services is to properly assess the risk and design a system for the operation of work in technological operations to reconcile often conflicting goals. Legal or safety correction is often at odds with the demands and needs of company employees and their management. Therefore, setting the correct safety limits is not easy and no longer costly. It is of the utmost importance to know the risk and apply safety measures to achieve the level of residual risk that is tolerated by the company.

Correct risk assessment in the technological processes of working with wood includes, among other things, fire safety, but no less important role is to establish the fact of the risk of explosion of agitated dust, even materials that do not normally pose a fire risk.

The explosion itself can have a negative impact on life and human health, the destruction of property, animal lives and damage to the production process. It is essential that in operations where there is an increased likelihood of an explosion, employees are informed and properly trained to work in hazardous environments.

The aim of the study is to identify the danger of explosion when working in a woodworking hall and to propose measures to minimize the occurrence of an adverse explosion event. 3D modelling of the production hall project helps to determine technological, organizational, and legal measures more easily for fire and explosion protection.

Implementation of the latest technologies in the woodworking industry

The use of the latest technologies in the wood industry in our country and in the world is still at a relatively low to very low level. The bulk of the inclusion of the 4.0 technological revolution includes modern wood processing equipment and a support team for controlling these devices. These are mainly computer-controlled machines (CNC), robotic production lines, intelligent technological spaces capable of controlling the flow of material, ordering system or security system.

The problem of the absence of autonomous technologies may be insufficient use of the economic, or educational potential of the country, as well as the strategic position of the state or other factors that affect the maturity of IT in the country. Finally, it is a politically, autocratically, or humanely motivated intention to leave work to people and not to machines. In this sense, Gazquez et al. (2021) assessed the lack of skills in the areas of key enabling technologies (KET) following the 4.0 (14.0) industrial revolution in higher education. The evaluated sectors include the skills of university graduates in the wood and furniture industry and their level of implementation regarding the latest technological trends.

According to Kropivšek and Grošelj (2020), the situation in Slovenia is at an advanced level of use of information technology and artificial intelligence. The research examined the digital development of the Slovenian wood industry, in particular the implementation of the Industry 4.0 concept in practice. Within this, the implementation of specific technological pillars with an emphasis on intelligent factories and intelligent innovative products was studied.

2 Experimental part

The production of children´s playgrounds can be realized using various materials. The material used is metal, plastic or wood. In the given operation, children´s playgrounds are mainly made of agate wood, due to its relatively good availability in the Slovak Republic, affordability, and very high durability.

2.1 White agate (Robinia pseudoacacia)

The authors Maľová et al., (2018) states that the original occurrence of this wood is in the southern part of the North American continent. The tree grows to a height of 25 m. Agate wood consists of three parts, bark, white and marrow shown in figure no. 1.

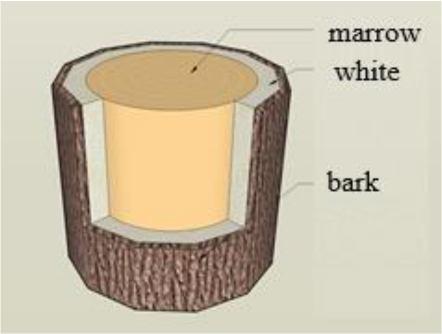

Fig. 1 Composition of agate wood

The agate white wood is hard and heavy. It is suitable for carpentry processing, splitting but also for surface treatment. During impregnation, it shows a high absorbency of the impregnated substance. Drying is slow. It is resistant to most types of biotic pests. Wood Agate white (Robinnia Pseudoacacia) is one of the most durable species of wood that will last 80 years without treatment. If the agate wheel is under water, its shelf life exceeds 300 years.

2.2 Machinery in the wood hall to produce children´s playgrounds

Debarker

For the purposes of wooden constructions, agate tree trunks are stripped of bark and white, which is the purpose of the debarking device shown in figure no. 2.

Fig. 2 Debarker (Interforst)

Horizontal band saw

This frame horizontal saw figure no. 3 is a movable band saw used to cut the entire log along the horizontal direction.

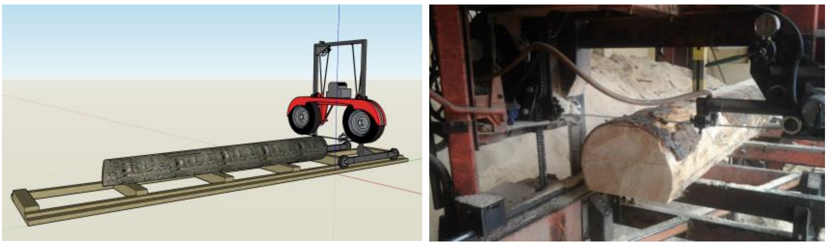

Fig. 3 Horizontal band saw (Rezivo a gáter)

Angle grinder

Angle grinder figure no. 4 is a tool used to smooth a surface by grinding by rotating a grinding wheel.

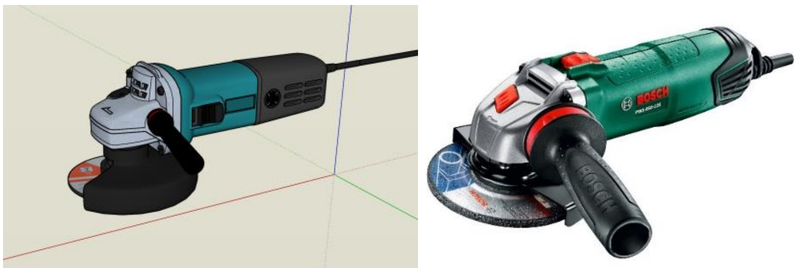

Fig. 4 Angle grinder (Interforst)

Tail saw

This type of saw shown in figure no. 5 is a straight cut but is mainly used for cuts with an atypical motion trajectory.

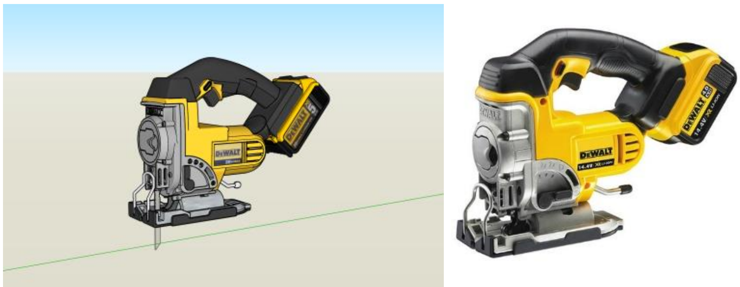

Fig. 5 Tail saw (Interfosrt)

2.3 Classification of areas with explosive atmospheres

When wood lumber is treated with machinery, wood dust is created which, when mixed with air, creates an explosive atmosphere. To assess the risk of explosion, areas with an explosive atmosphere must be classified as areas with a risk of explosion into three zones. Zone 20 is a space in which an explosive atmosphere composed of a mixture of combustible dust and air in the form of a cloud occurs continuously, for a long time or frequently. Such places generally occur only inside the wood sawdust extraction line, inside the wood dust extraction pipe or the fine wood waste container and near the wood dust production plant in its vicinity. An example of zone 20 is shown in figure 6.

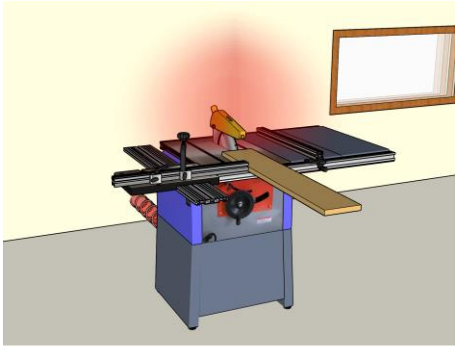

Fig. 6 Circular saw - Zone 20

Zone 21 shown in figure no. 7 is an explosive environment forming agitated combustible dust mixed with air, the occurrence of which is occasional. The occurrence of such places is within the production hall where combustible dust with air swirls and includes the entire interior of the production hall. Above all, however, these are places around the working machines.

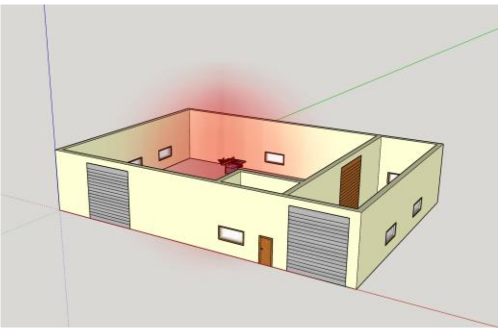

Fig. 7 Production Hall Zone 21

Zone 22 is an explosive atmosphere forming turbulent combustible dust in admixture with air which is not expected to occur, but even if it does, it is only for a short time. Such a place represents the space of the production hall where the dried lumber shown in figure no. 8.

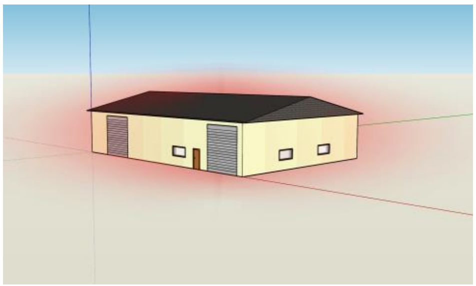

Fig. 8 Production Hall Zone 22

Tab. 1 Categories of equipment for explosive atmospheres (Nariadenie vlády SR č. 149/2016 Z.z.)

Group	Category	Use	Degree of protection	Explosive zone
I.	M1	mines	very high degree of protection	
	M2	mines	high degree of protection	
II.	1	gas and dust explosive atmosphere lasting continuous or long period of time	very high degree of protection	zone 0 (G) zone 20 (D)
	2	gas and dust explosive atmosphere occurring occasionally	high degree of protection	zone 1 (G) zone 21 (D)
	3	gas and dust explosive atmosphere occurring rarely and for a short time	normal degree of protection	zone 2 (G) zone 22 (D)

2.4 SketchUp Modelling Program

SketchUp is a 3D modelling program owned by software company Trimble Inc. based in Sunnyvale, California, USA This program is used to obtain detailed product diagrams and model three-dimensional sculpture diagrams. It is characterized by a simple user interface and orientation in space (SketchUp, 2021). SketchUp is a highly intuitive program, it is possible to download a plethora of add-ons (plugins) that help create better models in a more efficient way (Saymote, 2017).

SketchUp is a user-friendly open-source program. It can be widely used at the educational level as well as at the professional level. It offers demonstration of real objects in a virtual environment to understand and present the relationships needed to create the most virtual reality of real projects at the time of their development to minimize costs and time. Example of use in practice in modelling a woodworking workshop figure no.9.

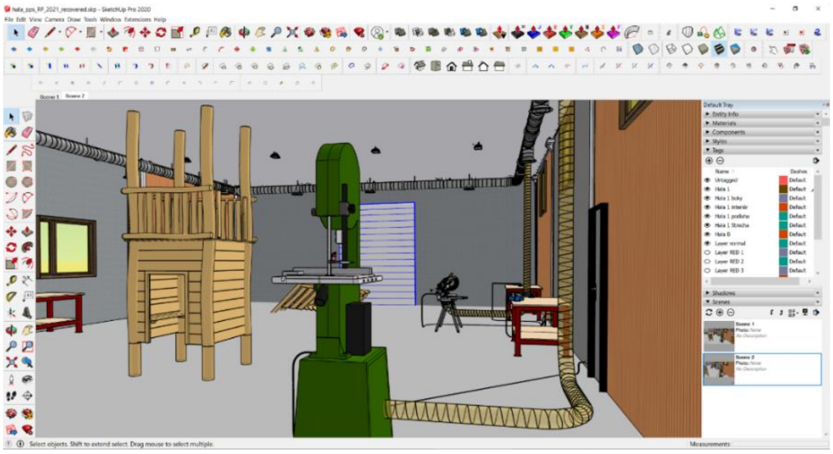

Fig. 9 SketchUp model Wood workshop

3 Results

When assessing the risk of explosion, it is necessary to consider potential locations of hazardous atmosphere by including places in the relevant explosion hazard zones, re-evaluate the production process, equipment used and a system of preventive measures to minimize the risk of explosion. An important part is also to acquaint employees with the presence of an explosive atmosphere by proper training and behaviour in the workplace according to the principles of health and safety.

3.1 Classification of carpentry workshop premises

When assessing the risk of the probability of the occurrence of an explosive atmosphere and considering the points of procedure according to Government Decree no. 393/2006 Coll. I designed the occurrence area of zone 20 in the 3D environment using the modelling program SketchUp. The presence of an explosive atmosphere in this zone is continuous or almost continuous during operation of the machinery.

Zone 20 is in model figure no.10. In the woodworking workshop, it is depicted with a pink-red area. This area is formed by a space 1.5 m from the center of emitting dust particles.

Fig. 10 Production Hall model - Zone 20

Zone 21 is an area with an explosive atmosphere formed by a mixture of agate wood dust with air and the occurrence is occasional. Such a space is visualized in the present hall of the production building by the area of faint red colour in figure no. 11 in the vicinity of 3 m from the point of dust production.

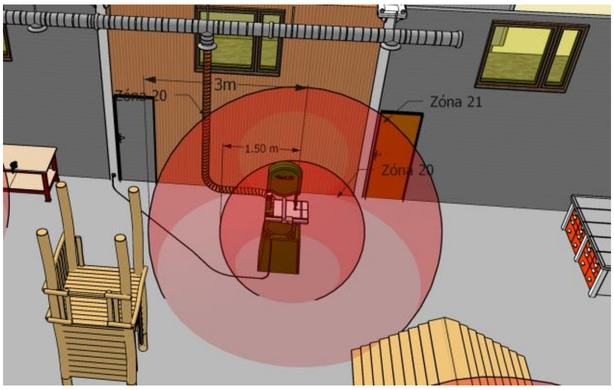

Fig. 11 Production Hall model - Zone 21

The area shown in Fig. no. 12 is a zone 22 in which a hazardous atmosphere is not expected to occur and, if such a situation occurs, it is only for a short time.

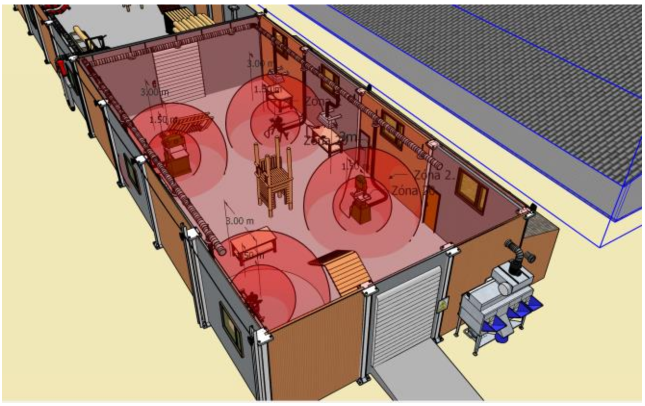

Fig. 12 Production Hall model - Zone 22

3.2 Design of equipment intended for zones according to the probability of the occurrence of a hazardous explosive atmosphere

For devices where many residues in the form of wood dust is generated during work and their position is anchored within the hall, a central dust extraction by means of a vacuum airline is designed. Three manual extraction stations connected to a central extraction are reserved for manual woodworking equipment.

Within the production hall, a band saw, a woodworking planer and two circular saws, two stations for work with hand tools are equipped with this air extraction device figure no. 13. Suction of machinery is ensured by means of a polyurethane flexible hose reinforced with a steel wire in the shape of a spiral. It is primarily intended for sawdust extraction, capable of withstanding vacuum, connected to a galvanized steel pipe. This air duct opens from the outside of the hall at the location of the cyclone separator. The arrangement of the machinery within the hall is shown in figure no. 13.

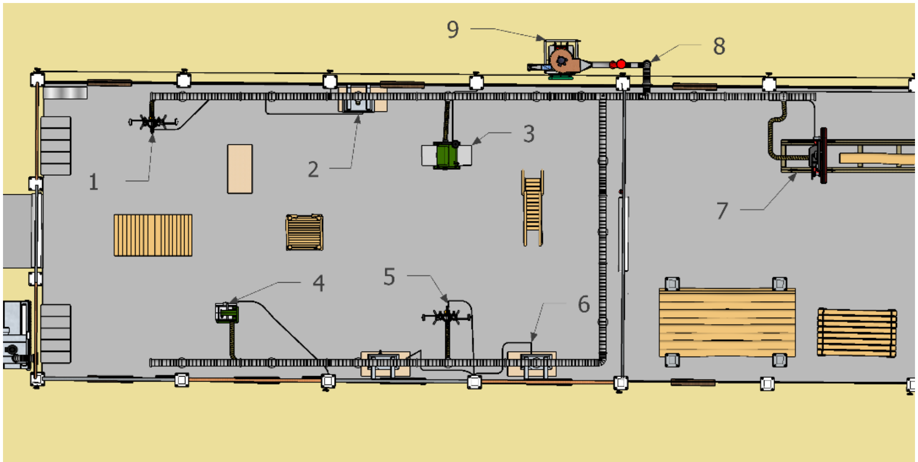

Fig. 13 Production hall - top view

1. Circular saw
2. Tail saw
3. Planer
4. Vertical saw
5. Circular saw
6. Angle grinder
7. Horizontal saw
8. Air conditioning
9. Cyclone separator

The horizontal band saw located in the eastern part of the hall is shown in figure no. 14 and is also part of the proposed air conditioning. A dangerous explosive zone has not been designed for the given facility, as raw wood is processed here, the moisture of which is many times higher compared to dried lumber. Such wood does not create an explosive atmosphere during processing.

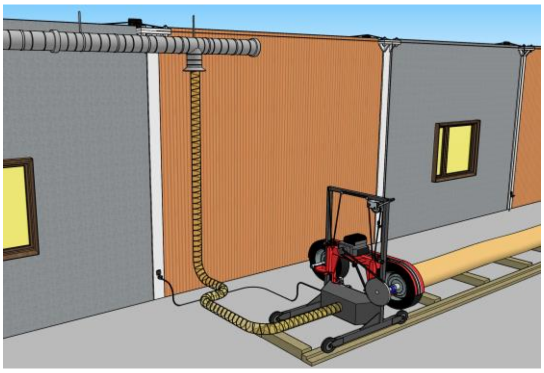

Fig. 14 Extraction - horizontal saw

Cyclone sawdust separator

Ventilation extraction of sawdust and small pieces of wood works on the principle of a vacuum system, the operation of which is ensured by an 18-kW electric motor. It is part of a cyclone sawdust separator. It is designed for dust-explosive environments shown in figure no. 15. This device is also equipped with a relief membrane which, in the event of an explosion in the cyclone separator, ruptures and mitigates the deformation effects of the pressure wave.

An anti-explosion chimney is designed on the exhaust pipe, located outside the building and its function is to alleviate the explosion by releasing the pressure wave of the explosion front into the safe zone due to a change in the direction of the exhaust air flow.

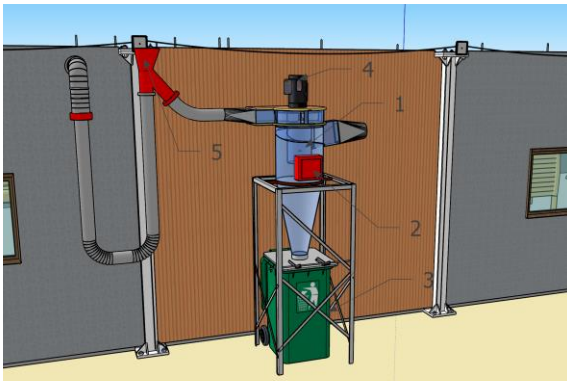

Fig. 15 Cyclone sawdust separator

1. Cyclone sawdust separator
2. Relief membrane
3. Wood dust container
4. Electric motor
5. Anti-explosion chimney

Humidification system

Humidification system within the hall, ensures high-pressure spraying of water in the form of water mist. Its main task is to create water particles that bind dust and thus significantly reduce the risk of explosion in the atmosphere.

Other advantages of such air humidification include in particular:

• reduction of the probability of static electricity

• increase of comfort of inhaled air, which has a significant impact on the health of employees
• increase of functionality of machines operating in significantly less dusty environment

Fig. 16 Humidifying equipment

3.3 Organizational and technical measures

When working in potentially explosive atmospheres, it is also necessary to minimize the occurrence of initiating sources of explosion, such as hot friction surfaces, static electricity, sparking of electrical equipment, mechanical spark, lightning, or open fire in each production hall operation. We can minimize the occurrence of these sources of initiation by training employees in terms of safety and health at work and the risk of explosion.

The employer is also obliged to mark the place of entry into the production hall where a dangerous explosive environment arises according to the ATEX directive with a warning sign placed at each entrance to the given space shown in Figure no. 17.

Fig. 17 Marking of entry into an explosive atmosphere

3.4 Evaluation of the measures taken

In table 2, there are machines that are used in the production hall for processing lumber and their classification into the appropriate category of explosion protection according to the environment in which they are located during the production process.

Tab. 2 Summary table of machinery in the production hall

Device number	Machinery	Created explosive environment	Device category
1	Band saw	zone 20	1D/ IP64
2	Circular saw 1	zone 20	1D/ IP64
3	Circular saw 2	zone 20	1D/ IP64
4	Planer	zone 20	1D/ IP64
5	Angle cutter	zone 20	1D/ IP 64
6	Tail saw	zone 20	1D/ IP64

The adoption of technical and organizational measures in the woodworking workshop to produce children´s playgrounds involve the inclusion of machinery in individual danger zones with the appropriate certification, which declares safe use in the given environment. Explosion-proof protection elements, such as a relief membrane and an explosion-proof chimney, have been designed for the suction device to minimize the consequences of a possible explosion. The entrance to the hall is marked by the appropriate danger zone, which clearly defines the area with an explosive atmosphere. We considered that the knowledge of employees working in an explosive environment is insufficient and therefore training of employees in terms of explosion protection and health and safety was proposed. For machinery that does not have a fixed location within the production hall and creates an explosive environment, a local exhaust device was designed, the efficiency of which within the hall was significantly supported by the proposed air humidifier, which largely eliminated the occurrence of frequent static sources of static electricity. In the partition of the separated eastern part of the production hall, we did not mark the horizontal machinery of the band saw as the cause of an explosive atmosphere, as the cross-section of the raw log reaches many times higher humidity than the dried lumber. Applying paint within both parts of the hall also does not pose a risk of explosion, as the paint is water-soluble and does not create an explosive atmosphere.

4 Conclusions

The European Directive 99/92 / EC (ATEX 137) was used for the elaboration of a written document on explosion protection, which is transposed in the Slovak Republic to the National Council of the Slovak Republic no. 393/2006 Coll. On minimum requirements for ensuring safety and health protection at work in an explosive environment.

Real space modelling while maintaining the dimensions of the actual hall and interior, with the support of CAD 3D technology in the modelling tool SketchUp Pro 2020, significantly helped to achieve the assessment of the risk of explosion in the space. The production process of processing wood parts takes place within the production hall and poses a significant risk of explosion of wood dust due to mechanical processing of wood raw material to produce playgrounds. The model of the hall contains proposals for technical and organizational measures. The individual explosion hazard zones were modelled and graphically represented. By minimizing the risk, we protect the life and health of employees, technology and thus the production process itself.

The use of modern 3D modelling technology in industry, provides a realistic idea in the construction and modification of buildings and in the implementation of safety designs. It provides accurate plotting of areas and helps determine the occurrence of hazardous areas of explosion. It enables verification of proposed measures and implementation of changes in the virtual environment with minimization of financial and time costs.

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Increase Efficiency in Extinguishing Wildland Fires with Light Forest Fire Trucks

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Short report

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Abstract

Climate change is affecting all countries of the world. An increase in temperature and a decrease in the moisture content of the vegetation cause an increase in the burning rate of fires. To fight wildland fires at least as effectively in the future as we do today, we need vehicles. This article explores effective tools for this. By researching the relevant literature, drawing logical conclusions, and performing simple mathematical calculations, the author determines what are the most important features, also known as firefighting tactics, that are required to design a light forest firefighter that is optimal for forest firefighting. The result of the research is a light forest fire truck capable of carrying 6 firefighters and transporting at least 1000 liters of water in difficult terrain. By using a light forest fire truck, the physical size and weight can also be reduced while the average speed increases.

Keywords: Climate change; efficiency; light fire truck; wildfire

1 Introduction

Climate change, and the warming that comes with it, is a current problem that we can only very little influence in the light of our current experience, but it will present us with challenges in the foreseeable future that we must be prepared for today. If the climate in Central Europe changes according to the current trend, and this increases the average annual temperature, it will necessarily lead to an increase in the duration of periods of increased forest fire risk. In addition, a possible vegetation fire will be more intense, within decades even more intense than any domestic forest and vegetation fire so far. This is supported by the figure below, which clearly favours the development of more frequent and intense fires (Bodnár, Bérczi, 2018; Debrecenweet al., 2017; Pántya, 2018)

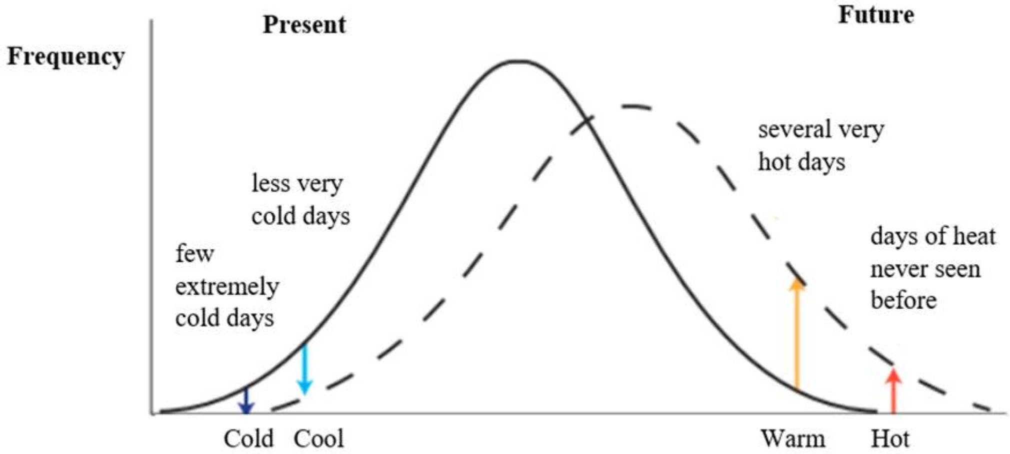

Fig. 1 Mean temperature change and frequency and their effects

Not only does the table predicts days of unprecedented heat, but we can see that the frequency of currently high record high temperatures can be many times higher than before. In addition, the expected amount of precipitation will not change significantly, but the number of precipitations with light and moderate precipitation will decrease on average, while heavy rainfall will be more frequent. As a result, the moisture content of the vegetation will be lower and thus the risk of fire will increase significantly, in addition, it is likely that the intensity of the burning itself will be higher, which means a higher rate of spread (Pántya, 2016; Nagy, 2004).

The motivation of the research is the legitimate demand of society to carry out firefighting tasks at least as efficiently in the coming years as we do now. It logically follows that we need improvement. The tools and procedures needed for a successful intervention need to be developed today. This is also important to enable interveners to carry out their work with the least possible physical strain.

The objectives of the author are:

- determine the increase in fire intensity, the size of the area affected by the fire, in a specific case.
- To establish that by using a vehicle with a higher average speed and a smaller size, it is possible to start extinguishing a more intense fire under similar conditions as in the current conditions.
- Identify the vehicle from which the light forest fire truck can be constructed.

2 Material and Methods

At the time of writing, we have collected the relevant characteristics of vehicles currently used in forest fire extinguishing. Based on my own professional experience and logical conclusions, we have selected the properties that make a vehicle suitable for transporting water and firefighters as close to the fire as possible. We simulated a theoretical fire propagation using simple mathematical calculations to determine how the extent of the fire changes when we arrive with a light forest fire truck instead of a medium-weight fire truck.

Damage caused by an outdoor fire increases in proportion to the total duration of the fire. In Central Europe, thousands of outdoor firefighters successfully extinguish each year. Based on this, we can see that with the current technical background, the training of the staff, and the physical condition, the current tasks can be solved. Over the years and decades, the topographic conditions will not change significantly, nor will the density of the road network. We assume that the number of intervening fire-fighting units will not decrease in the future either. If we accept these conditions, we can conclude that it will take a similar amount of time to arrive at the scene of the damage as at present (Rácz, 2018; Rádi, 2016).

Let us see what differences we can experience at the same time of arrival if we must extinguish a fire under similar conditions but more intensely. We want to illustrate the problem with a specific example.

We used simple mathematical calculations for the calculations. We based it on a theoretical fire propagation, according to which fire spreads at a constant rate in all directions under unchanged meteorological conditions (Teie, 2018).

$$R_{fire} = t_{all} * v \quad (1)$$

$$K_{fire} = 2 * R_{fire} * \pi \quad (2)$$

$$A_{fire} = R_{fire}^2 * \pi \quad (3)$$

Low intensity of fire (nowadays)

We calculated with an average fire spread nowadays, this is 2 \frac{m}{min}. The fire squad is alarmed 10 minutes after the fire inflammation. The duration of the approach to the fire was determined to be 40 minutes due to the varied road conditions. Using equations (1), (2), and (3), we determined the parameters of the fire at the time of arrival (Teie, 2018; Restás et al., 2015).

$$R_{fire} = 50\, min * 2\, \frac{m}{min} = 100\, m$$

$$K_{fire} = 2 * 100\, m * \pi = 628{,}4\, m$$

$$A_{fire} = 100^2 * \pi = 31400\, m^2$$

Even in a relatively low intensity fire, firefighters face a sizeable fire front.

Medium intensity (future, more intense fire)

When analysing the much larger temperature data, it is difficult to determine exactly how much more intense the combustion will be, but a spread rate of one and a half times seems realistic to me.

In this case, the rate of fire spread is 3 $\frac{m}{min}$. As in the previous case, the fire brigade will be alerted 10 minutes after inflammation. The road conditions are the same, so the duration of the approach is the same, a total of 40 minutes. Using equations (1), (2), and (3), we can determine how much the parameters of the fire have changed (Teie, 2018).

$$R_{fire} = 50\, min * 3\, \frac{m}{min} = 150\, m$$

$$K_{fire} = 2 * 150\, m * \pi = 942\, m$$

$$A_{fire} = 150\, m^2 * \pi = 70650\, m^2$$

In this case, a much larger fire front is obtained, and while the circumference of the fire increases in direct proportion to the intensity of the burn, the size of the area already burned exponentially. This is a condition experienced on arrival at the scene of a fire, and firefighting only begins after that.

So, if we have to extinguish a more intense fire in the same area, we will obviously have to deal with more damage, of course, assuming that the effectiveness of the extinguishing is similar to the current one. In my opinion, the period of free spread of fire should be reduced to the shortest possible time, which is easier to do than trying to reduce the size of the burned area (and thus the damage value) only with the efficiency of firefighting.

This can be solved by using vehicles that travel at a higher average speed than at present, and whose physical dimensions and weight are less than those of the fire trucks currently in use, making it less likely that a pedestrian approach will be required (Teie, 2018; Restás et al., 2015).

Design of a light forest fire truck

Extinguishing outdoor fires is often a logistical problem. The right forces need to be delivered to the right place as soon as possible. The problem arises right here, the off-road capability of the mid-weight fire trucks currently used in the largest numbers does not allow interveners to be transported right next to the fire. This is mostly a protracted pedestrian approach, and dirt roads also run at low speeds (Zsitnyányi, 2020).

Tab. 1 Parameters of different fire engines

Type	Crew (person)	Amount of water (m^3)	Weight (t)	Wide x high (cm)	Average speed on dirt road (km/h)
Rába R16	6	4	16	2500 x 3380	20
Unimog U500	3	2,7	16	2500 x 3500	20
Vw Amarok	4	0,12	2,5	2000 x 1700	40
Light Truck	6	1	3,5	2400 x 1800	40

The solution is a vehicle that can reach higher speeds than it does on the dirt road and can also travel in terrain where current vehicles no longer do. In addition, its small weight and size do not hinder the narrow forest, mountain roads. Most Pick-Ups meet these criteria. Among these vehicles are those that can carry up to 6 people and can carry up to 1,000 l of water. Dodge RAM meets these parameters.

While the average travel speed of medium-weight fire engines is set at 60 km/h by fire-safety plans, in practice it drops to just 20 km/h when driving on dirt roads. Leaving the dirt road is often unsafe, off-road the structure, weight and center of gravity of the vehicle do not allow driving, so a pedestrian approach is required, which is about 4 km/h.

Smaller Pick-Ups outperform this, easily reaching 70 km/h. They are also capable of an average speed of at least 40 km/h on dirt roads and a speed of at least 10 km/h on off-road.

To find out whether these speed differences represent a significant difference in practical use, we performed a calculation in which the assumed fire is located 15 km from the fire department. This must be overcome by 10 km of asphalt road, 4 km of dirt road, and 1 km of terrain (Zsitnyányi, 2020).

The results obtained are summarized in a table.

Tab. 2 Average speed on the different quality of road

Type, and lenght of road	Mid-weight fire truck (min)	Light fire truck (min)
Asphalt road 10 km	10	8
Dirt road 4 km	12	6
Off-road 1 km	15	6
Summarise	37	20

The difference is significant, it would only change if the fire was located very close to the fire department and could be approached along good quality roads. However, we know from experience that these conditions rarely occur in the case of forest and vegetation fires.

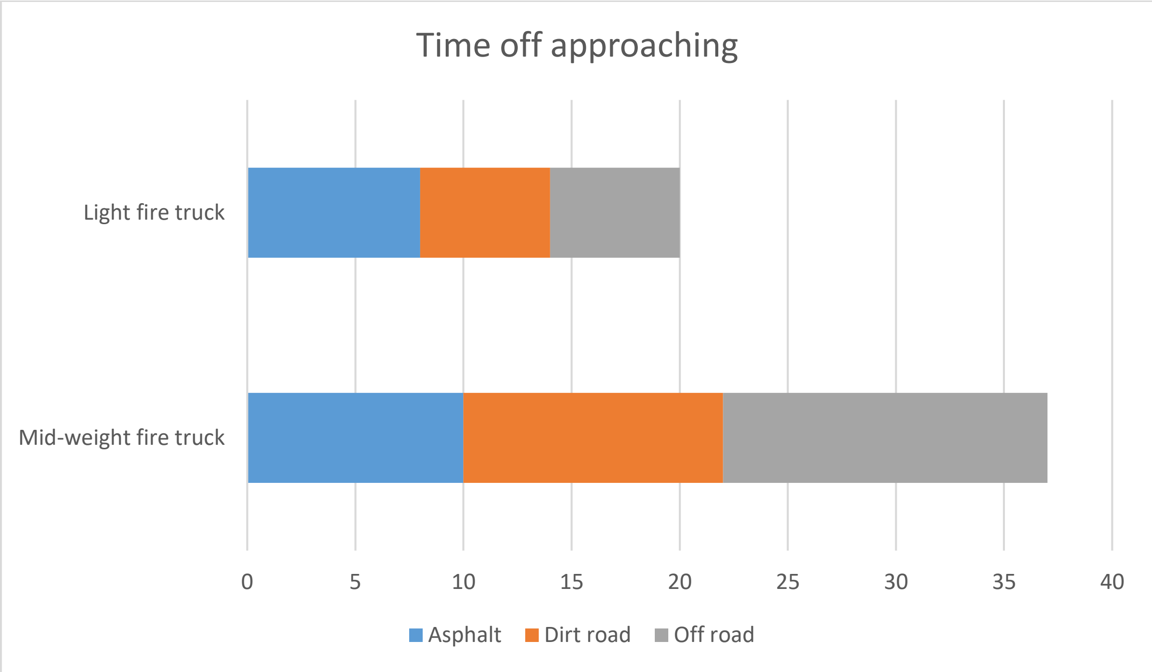

Fig. 2 Time of approachig on different quality of roads

3 Results and Discussion

The question is whether the advantage of a light off-road vehicle traveling at a higher average speed is sufficient to do not have to start extinguishing a fire in a more unfavourable situation than at present in the event of more intense fires. This is a condition that the burned area and the damage caused should not be greater than at a lower rate of fire spread, so that the subsequent firefighting can be at least as economically efficient as it is today.

The lower fire speed of 2 m/min and the longer total fire time of 50 minutes in the case of free fire spread approaching medium-mass fire engines approached, with a fire circumference of 628 m and an area of 31,400 m^2.

By calculating a fire speed that is one and a half times more intense, we can examine whether the area affected by the fire at the time of arrival can be reduced to at least 2 m/min, or possibly below, by using Pick UP, thus reducing the time of arrival.

Using equations (1), (2) and (3) again, but already considering the shorter arrival time, which is 20 minutes, it is possible to calculate how large the parameters of the fire will be at the intensity of 3 m / min, and the described 15 within a kilometer distance.

$$R_{fire} = 30\,p * 3\,\frac{m}{p} = 90\,m$$

$$K_{fire} = 2 * 90\,m * \pi = 565\,m$$

$$A_{fire} = 90\,m^2 * \pi = 25434\,m^2$$

Fig. 3 Light Forest Fire Truck

We can see that as the exit time shortens, the area affected by the fire is significantly reduced. This means that tactically in this case, the unit arriving with the Pickup will not start at a disadvantage, despite the more intense spread of fire. This can be a solution to the problem, and even the elimination of the damage can be started from a more favourable situation in case water extinguishing is used.

However, it is worth noting that the cost of purchasing and operating a light forest fire Truck is significantly lower than that of larger Fire Trucks. However, it has significant benefits in extinguishing outdoor fires (Restás, 2020; Zsitnyányi, 2020).

Optimized forest fire truck

Based on the values obtained and my practical experience, we try to determine what conditions a forest fire vehicle should meet. In the absence of suitable off-road vehicles, the lengthy pedestrian approach favours the free spread of fire. Upon arrival at the fire, the area of the fire is not immediately visible due to the articulation of the terrain, so reconnaissance may be delayed until the fire chief is satisfied of the true area of the fire. Only then can you determine the forces and tools needed to put out the fire. Again, this only favours the spread of fire.

Intervention is most often hampered by the fact that we cannot approach the fire with the water tender so much that we can use the quick-acting beams and must approach them on foot. The solution to this is a vehicle with adequate off-road capability, which is suitable for transporting 6 firefighters, is suitable for transport on narrow, mountain roads due to its size, and can transport the necessary professional equipment as well as extinguishing water (NFPA 1977; Zsitnyányi, 2020).

Fig. 4 Dodge RAM fire engine

Examining the properties of several types, we found the Dodge Ram Tradesman to be the most suitable vehicle for the purpose. Its unique feature is that it can carry 6 people in two rows of 3 people.

Its height is between 1800 and 1900 mm depending on the design (this also depends on the size of the rim or tire), it is much lower than any forest fire truck used so far, therefore its center of gravity is low. However, depending on the body, its load capacity is approximately 1850 kg. This capacity allows the vehicle to carry equipment used to extinguish forest and vegetation fires, and a full swarm of dimensions, and off-road capability to transport the unit as close as possible to the fire. In my opinion, such a vehicle would be a great tool to use with a high-pressure extinguisher and special equipment for extinguishing forest fires. Due to its load capacity, it would be able to deliver up to 1000 l of extinguishing water in addition to professional equipment.

The disadvantages of the Volkswagen Amarok fire trucks currently in service are the low number of crew and the low transportable weight. In my experience, a crew of four and only 120 l of extinguishing water are not enough to put out intense fires. The basic unit of the fire force is the squad. If a start must be split to be transported by a light vehicle, the distribution of forces is complicated and time consuming. The amount of water supplied is sufficient for less than 3 minutes of continuous operation, considering the nozzle output of 40 l per minute. Even an ATV would be able to carry this amount of water, at a lower cost, and even on more difficult terrain (Zsitnyányi, 2020; NFPA 1977; Restás, 2020).

Fig. 5 Fire fighting with ATV

With what has been described, we wanted to illustrate that a small fire truck can be used in many ways and can make the intervention fire units more mobile. But the condition for this is that the swarm comes to the fire with the light forest agent and delivers the right amount of water. The solution is not to keep light forest fire trucks in service as a special fire truck, but to have the opportunity to decide, based on the professional experience and local knowledge of the fire squad leader, to go to the open fire with a light forest agent instead of a universal fire truck.

Firefighters could respond quickly to changed conditions when using a vehicle like this, and quick redeployments could be resolved. They could get as close to the fire as possible, shortening the otherwise lengthy pedestrian approach and thus the phase of free spread of the fire. Such light-weight fire engines are used in many countries, including the poorest regions of Africa, because of their advantageous properties and simplicity, as well as affordable goods.

If a light forest fire truck with 1000 gallons of water is equipped with the necessary hand tools, you can extinguish a fire much more effectively than a mid-range fire truck (Zsitnyányi, 2020; NFPA 1977; Restás, 2020).

Fig. 6 Portable Bush Fire Unit

Many companies specialize in the manufacture of fire-fighting equipment that can be operated from simple IBCs. These are universal devices, installed on site, or even mounted on a platform, with a hose length of up to 100m. Equipped with an ultra-high-pressure pump, it allows water-saving firefighting and is easy to handle due to its small diameter, lightweight fire hose. The weight of such a device in the case of an empty tank is only 65 kg, so it can even be manually lifted or removed from the vehicle if the intervention requires it. This may be necessary if citizens or even fire forces must be evacuated from the area affected by the fire. Fortunately, such situations are rare in Central Europe, but not unprecedented, and may become more frequent as the intensity of fires increases (Zsitnyányi, 2020; NFPA 1977; Restás, 2020).

Indirect approach and post-firefighting work also make good use of light vehicles, these activities can be performed effectively on the front line of the area closely affected by the fire, so a firefighting vehicle capable of approaching any point in the terrain is required, medium mass fire trucks are rarely suitable (Teknős, 2018).

Fig. 7 Indirect approach

4 Conclusions

Climate change is affecting all countries of the world. An increase in temperature and a decrease in the moisture content of the vegetation cause an increase in the burning rate of fires. To tackle outdoor fires at least as effectively in the future as we do today, we need new tools and new solutions.

Extinguishing outdoor fires can be done more effectively by looking at the features of a fire truck that can be used to start extinguishing a fire sooner. One of the most critical properties is the maximum average speed available, but not on an asphalt road, but over the entire distance. We can significantly increase this if we can leave the asphalt road, drive on dirt roads and then in difficult off-road conditions, and transport at least 1000 l of water next to a firefighting squad

My calculations proved that even with increasing fire intensity, we can start firefighting under conditions like the current one. Another advantage is that if there is no need for a pedestrian approach, the fire water and equipment are located next to the fire, this again allows for time-saving tactical solutions, which further increases efficiency.

By using a light forest fire truck, the physical size and weight can also be reduced while the average speed increases. In addition, the cost of purchasing and maintaining a light vehicle is significantly lower than that of a heavier mass fire truck. This means that more could be obtained from a light vehicle, and not only fire departments but also forestry and volunteer fire departments could be equipped.

Extinguishing outdoor fires is primarily a logistical problem: the right forces need to be delivered to the right place and at the right time, which is the key to success. We therefore see the future of outdoor firefighting not in the use of heavy-weight, high-volume fire-fighting fire trucks, but in fast-moving, well-equipped, large-scale interventions that can reach most points in the firefighting area and respond quickly to changing conditions.

Finally, we look back at the objectives.

- As the intensity of the fire spreads, the area affected by the fire increases significantly. It follows that there is a need to increase efficiency.

- With a significant reduction in approach time, the dimensions of the fire on arrival were smaller than they were in the case of a less intense fire. This can be achieved by using a vehicle that has a higher average speed and smaller physical dimensions.

- We examined the properties of several vehicles and found that the Dodge Ram can carry a squad of 6 firefighters and 1000 l of water. These features make it suitable for being the optimal fire truck for forest firefighting.

Based on the obtained results, we conclude that the light forest fire truck with the characteristics we have defined is suitable for solving our challenges in the coming decades.

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Libušín – Historical Building Fire

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Case Study

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Abstract

The case study deals with the analysis of the all-wooden object Libušín in Pustevny in the village of Prostřední Bečva in context: the architect and his work - fire - restoration of monument relationship. The Libušín was designed by Slovak architect Dušan Samuel Jurkovič. It was destroyed by fire in 2014 and subsequent this object was reconstructed. This case study is a good example of scientific reconstruction. For all repairs they have been complied with traditional handcraft techniques, using the original materials and technology. Also, the modern extinguishing technology based on a special inert gas and using a water fog low-pressure spray have been integrated for its fire protection into the future.

Keywords: Dušan Samuel Jurkovič; fire; Libušín; reconstruction

1 Introduction

Fires wooden historic buildings often represent an irreplaceable loss for our cultural heritage. When a historical object burns down, society loses not only material values, but also cultural values, i.e. a spiritual legacy that should be passed down from generation to generation. When future generations will no longer be able to admire rare murals or paintings, they will lose an important part of cultural identity. The protection of historical monuments is also specific in terms of the complexity of the intervention, due to the limited possibilities of arrival and access. Another problem is the protection of movable monuments inside these buildings, which must be evacuated in time in case of danger.

In recent years, there have been several devastating fires of wooden historic buildings in the Czech Republic, for example in 2002 the Church of St. Catherine's from the 16th century in Ostrava-Hrabová, in 2007 a bell tower from the 18th century in Železný Brod, in 2014 the tourist hostel Libušín in Pustevny, and also in 2017 the Church of the Corpus Christi from the 16th century in Třinec-Guty (Generální ředitelství HZS ČR, 2021; Otrusina et al., 2014; Nedělníková, 2017). Regardless of the cause of the fire, none of these buildings was able to be extinguished in time so that their historic structures and decoration remained undamaged.

Despite the destruction of the historic building, on the other hand, we could also perceive the effort to restore the buildings destroyed by fire. To this day, in the form of a replica of their original building, the church of St. Catherine in Ostrava-Hrabová (in the years 2002-2004), the cottage Libušín in Pustevny (2016-2018), and also the Church of the Corpus Christi in Třinec-Guty (2020-2021) was built.

In this case study, we will point to a good example of the reconstruction of a building destroyed by fire, in the view of the architect and his work - fire - restoration of a monument with the aspect to the concept of spark (impulse) and its significance for the origin, damage and restoration of the historic building Libušín in Pustevny in the Czech Republic.

2 Methods

Methodology of work consists of the following analysis of the available books, magazines and internet resources:

a) an analysis of an all-wooden object of a tourist canteen Libušín, which projected Dušan Samuel Jurkovič,

b) an analysis of the fire of that object

c) an analysis of the reconstruction process and its future fire protection.

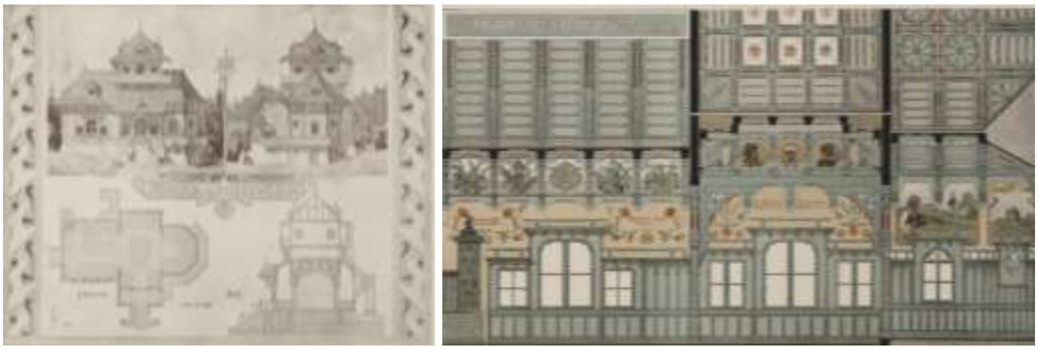
3 Results and Discussion

3.1 An architect Dušan Samuel Jurkovič and his Libušín

The first symbolic spark in the form of interest for wooden buildings appeared at a young age architect Dušan Samuel Jurkovič. He came from a very nationally aware family. He was born on August 23, 1868 in Turá Lúka and grew up in Brezová pod Bradlom. His father was a strong patriot and his mother was an expert in folk art. During his studies, he discovered the magnificence of folk wooden architecture in north-western Slovakia and the Moravian-Slovak border. He was especially interested in the wooden architecture of folk buildings in the Slovak unique village of Čičmany.

Already during his university studies at the State School of Crafts in Vienna, he became interested in wood working - carpentry work. In 1889, after a short stay in the Atelier of architect Blažej Bulla, he started practice in project office of architect Michal Urbánek in Vsetín, where he stayed for 6 years. In that time, he received a proposal for the hostel and dining room (Fig. 1, Tab. 1) on the Radhošť hill in the village of Prostřední Bečva. Jurkovič accepted this offer. These two buildings are considered to be Jurkovič´s most important works and thanks to them he earned the nickname Poet of Wood (Bořutová, 2009). He worked as an architect in three countries - in the Czech Republic, in Slovakia and in Poland. He was a prominent representative of Art Nouveau architecture. Unlike other Art Nouveau architects, he integrated many elements of folk wooden architecture into his projects. With the buildings in Pustevny – Maměnka and Libušín (opened on August 6, 1899), an architect Jurkovič shocked art theorists and also tourists.

The Libušín (Fig. 1) was built as a wooden log construction in the style of Folk Art Nouveau with a rich decor, which is typical for folk buildings in individual areas of Moravian Wallachia and Slovakia. The building had a stylish restaurant dining room with a capacity of 200 guests, which was built in the years 1897-1899 and named in honor of the Princess Libuše. There was also a kitchen, including food warehouses and facilities for staff, sanitary facilities for guests and a bar. The original building was followed by a separate technical background, which had brick perimeter walls with wooden cladding. The most valuable part of the dining room was the hall with richly decorated frescoes and sgraffitoes. They depicted motifs of Wallachian and Slavic legends, designed by the artist Mikoláš Aleš and painted by Karel Štapfer. An apartment was set up in the attic above the hall on the second floor, which in the time before the fire only served to store unused equipment. Above it was a lookout tower. The interior of the dining room was designed by the architect Jurkovič himself and consisted of three chandeliers, a sideboard, a greenhouse, a clock and 100 carved chairs (Hasalík, 2009).



(a) (b)

Fig. 1 (a) Original designs of Libušín, (b) Libušín's interior decoration (Jurkovič 1900).

The all Pustevny complex as a unique architectural and urban complex including log buildings in folk style (tourist hostels Maměnka, Libušín, Stará krčma, bell tower and chalet) designed by important architect Dušan Jurkovič. In 1958, it was inscribed as a cultural monument in the Central List of Cultural Monuments of the Czech Republic (LCM CZ) under No. 22962/8-295. Since 1995, it protected as a national cultural monument under No. 230 in the LCM CZ (Národní památkový ústav, 2021).

Among the significant changes during its use, we can mention changes in its colour. The original colour of the wooden elements designed by the architect Jurkovič in the interior as well as in the exterior was preserved until approximately the period of the First World War. A clear degradation of wooden surface finish was visible in photographs from Pustevny's visit with President T. G. Masaryk in 1928. Also the surface finish of wood of exterior elements (log beams, balconies, railings, columns, consoles, ceilings, painting of gables, etc.) based on oil paints was significantly damaged mainly by long-term weathering (Dvořák, 2019). Other significant damage of wooden elements by wood-destroying fungi led to an extensive renovation of the building, which was personally agreed upon after 1947 by the almost 80-year-old architect Jurkovič, who visited Libušín for the last time (Hasalík, 2009). Large reconstructions in object Libušín were in 1960 and from 1996 to 1999. Also in 2004, a complete remediation and sterilization of wooden elements infested with dangerous wood-destroying fungus (*Serpula lacrymans*) was carried out (Cultural Service s.r.o., 2007).

3.2 Fire of Libušín

The second spark was literally a spark, and it led to the active fire. At night of March 2-3, 2014, the fire of this building started. Firefighters from 13 professional and volunteer units took part (Tab. 1). However, the building was destroyed by a massive fire. The height of the ash locally reached a height of about 70 cm (Otrusina et al., 2014; Otrusina, 2015).

Tab. 1 Characteristics of fire of Libušín (Otrusina et al., 2014; Otrusina, 2015).

Libušín	
City	Prostřední Bečva
District	Vsetín
Country	Czech Republic
Description of the object	Tourist cottage with a dining room on the top of the hill Radhosť, detached building with an irregular floor plan with an area of 492 m^2, has one underground and three above-ground floors
Construction description	Wooden log construction in Art Nouveau style with many decorative elements
Fire brigade	Voluntary Fire Department (VFD) Prostřední Bečva, Fire Rescue Corps (FRC) Rožnov pod Radhoštěm, FRC Valašské Meziříčí, VFD Horní Bečva, VFD Horní Bečva, VFD Hutisko-Solanec, VFD Zubří, VFD Zašová, VFD Velké Karlovice, VFD Valašská Bystřice, VFD Frenštát pod Radhoštěm, VFD Trojanovice, VFD Karolinka
Time of declaration of intervention	00:17 03.03.2014
Time of arrival for the intervention	00:45 03.03.2014
End of intervention	12:40 03.03.2014
Total intervention time	12 h 23 min.
Intervening technique	Water tender
Number of firefighters	96
Affected area [m^2]	600
Used fire extinguisher	Water
Quantity [l]	20 000
Damage caused	80.5 million (approx. 3.1 million €)

In the time before the fire, the building was equipped with an Electric Fire Alarm Systems (EFAS) with outputs to the Integrated Security Centre of the Moravian-Silesian Region. Early intervention by fire brigades prevented the fire from spreading to Maměnka. According to the overall evaluation of the intervention (Otrusina et al., 2014; Otrusina, 2015), the negative specifics of this intervention were several facts such as strong wind, which supported the rapid development and spread of fire, long distances of fire brigades, elevation, which significantly limited the speed of older SDH units from the surrounding villages, the later arrival of altitude technology, the nearest underground hydrant malfunctioning, the high temperature in the attic of the building, and finally the information about the fire from the EPS to the Central Protection Desk was not transferred.

The fire was caused due to the unsatisfactory design of the chimney and the installation of the flue from the heating element. The air pocket in the chimney body was not insulated from the wooden structure. The contractor issued an inspection report on the lined chimney, stating that "the smoke ways are without obvious defects and safe". No appliance was connected to the chimney at the time of the inspection. Even though the chimney was not in accordance with the standards, a tiled stove was subsequently connected to it. No flue gas path revision was performed after the appliance was connected (Jiřík, 2014 cited in Otrusina, 2015).

3.3. The main principles for Libušín restoration

The restoration of Libušín as a national cultural monument was guided by the methodological procedure valid for museums in nature in the form of scientific reconstruction (Bryol et al., 2020). Its aim is to preserve as much as possible the original form of the building, including the originally used material and traditional technologies. The scientific copy is designed on the basis of survival and detailed documentation of the *in situ* original (focus, description, drawings and photographic documentations), material analysis, archival research and historical-ethnological research. The principles of the reconstruction of the Libušín building included:

• restoration of the original disposition of the building,

• removal of inappropriate interventions in the building and changes in color during the existence of the building,

• ensuring fire protection of the building according to the requirements of currently valid legal and technical regulations in the field of fire protection.

The fire protection of the Libušín building was based on the need to achieve the resistance of the wooden structure for 45 minutes, based on a properly selected type and location of a stable fire extinguishing system, or a combination of extinguishing agents (Masák, 2019). It was necessary to decide the function of the original tiled stove – with its original or only decorative function. An equally important decision was to determine the function of the restored building.

3.4. Comprehensive restoration of Libušín

Another spark in the analysis of the architect and his work - fire – restoration relationship was the impulse of people to restore Libušín. The speed, ingenuity and effort of people to support the public collection for its restoration clearly showed the remarkable value of this Jurkovič building. 9,926,175 CZK was collected during the public collection (from March 4, 2014 till March 3, 2017) (Koželuhová, 2018). The director of the Wallachian Open-Air Museum appointed a working group for the supervision of the professional restoration of the monument constituted by specialists from the Wallachian Open-Air Museum, the National Heritage Institute, the Monument Care Department at Zlín Regional Office, Fire Rescue Service of Zlín Region and from the Construction Department at Municipal office in Rožnov pod Radhoštěm. All members of working group were agreed on the restored building would correspond to the form of 1925 and that all works would comply with the rules of exemplary scientific reconstruction (Bryol et al., 2020).

The digital focus and processing of pre-project documentation was performed by the company Transat Architekti from Brno, which prepared a construction-historical survey of Libušín in the period 1886-2014. In 2016, architectural studio Masák & Partner from Prague as a winner of the tender was prepared project documentation for construction of the new Libušín and necessary technologies (Masák, 2019).

Initially, the foundations and torsion of Libušín were precisely focused, and subsequently was created 3D model using BIM software (Masák, 2019). The advantage of this software is the accurate visualization and placement of every single element in the object. This helped in the design of the fire protection system and engineering networks, their most suitable locations and at the same time hiding in the structures so that they do not interfere with the aesthetic elements of the structure. Based on the tender, the company Archatt from Brno was selected as the build contractor (Prudík, 2019). The reconstruction of the building began with the gentle dismantling and passportization of the preserved elements. Each wooden element was assessed in terms of fire damage, previous rot damage as well as in terms of the quality of its craftsmanship in previous reconstructions.

Only 12% of the original wooden structures and elements and approximately 83% of the original masonry parts of local sandstone have been preserved (Prudík, 2019). After cleaning the fire-affected place and during research and design work, the torso of the building was briefly covered with a steel structure.

During the construction of the new Libušín, traditional woodcraft techniques were followed, and the original materials and technologies were used (Bryol et al., 2020; Kloiber, 2020). One of them is that timber must be logging in the winter during the latent period, when there is a minimum of water and tissue in the tree trunk. This contributes to increasing resistance to wood durability. Therefore, the logging was in winter after a full month from November 2016. All wooden components in wet state were hand-worked, as was done at the time of the original construction. Hand-worked wood was used for the dining room building, the surface of which is smoothed by planing and not sanded. It affects not only the appearance of the surface but also its quality. In accordance with dendrological purposes, fir wood was used for parts of the dining room and spruce wood for other parts. The threshold beams in contact with the foundations were made of oak wood. The external staircase was made of spruce wood and the decorative elements in the windows were made of aspen wood (Prudík, 2019). Surface charred original wooden elements had to be cleaned to sound wood and their state was either used on its original place, or as material for another suitable place (Fig. 2a).

An important feature of Jurkovič's buildings is the color of the exterior cladding and interiors. Restoration surveys, laboratory analyses, photo surveys and, in close collaboration with conservationists and conservators, identified and selected nine color shades for surface coating of exterior elements such as perimeter cladding, brackets, railings, columns and for painting plant parts and geometric elements. Seven shades of the top color and three types of underpainting were identified, which were then applied in the interior. The color of Libušín returned to 1899. A manufacturer with a corresponding recipe for oil paints was found at Ottoson in Sweden (Matulíková et al., 2014; Dvořák, 2019). The interior decoration of the dining room, painting the walls with frescoes and sgraffitoes, was successfully restored to its original condition (Fig. 2b). According to the preserved drawings of the artist Mikoláš Aleš, their contemporary artists reproduced them.

(a) (b)

Fig. 2 (a) Log cabin wall with built-in original beams (Novák, 2018); (b) Paintings and frescoes in the new dining room, the vapour barrier is also visible in the lower part (Masák & Partner s.r.o., 2021).

Also, during excavation work was found shard from the original tiled stove in the dining room. According to its color and the rest of the floral pattern, the original lining of the new fully functional furnace was made. During the dismantling of the torso in the toilet, hidden original ceiling beams appeared under the plasterboard ceiling, flatly polychrome with plant motifs and dated 1891. These beams were preserved in original form and returned to the building in its original place. During the reconstruction, a private person offered to buy an original wooden cartouche with the emblem of the Pohorská Jednota Radhošť, which was planted in one of the beams (Novák, 2018).

According to Jurkovič's original designs and historical photographs, details were realized in the interior of the building that were not there before the fire, for example a glass ceiling in a dining room with colorful painted motifs, now made of fire-resistant glass 4 cm thick, a chandelier in the apside, which Jurkovič designed but never created (Prudík, 2019; Novák, 2018).

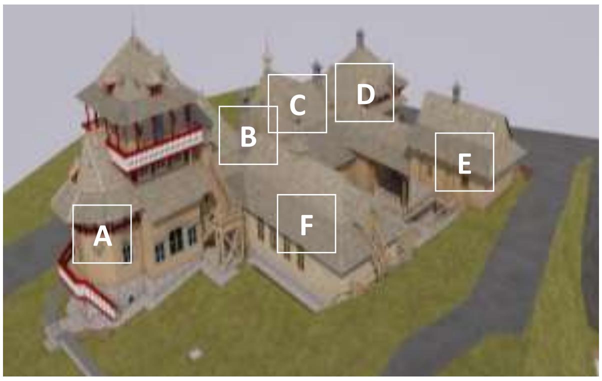
3.5. Fire protection of Libušín

A large concentration of people in Libušín puts special requirements on the timely and reliable detection of a fire, so that a similar scenario from 2014 never has to be repeated. Fire protection is important from the point of view of personal safety and protection of property.

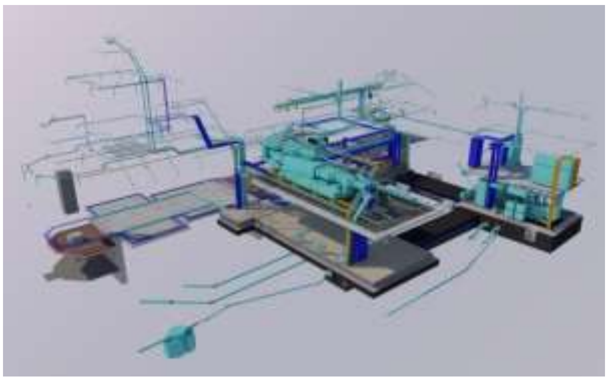
Combined EFAS detectors containing optical-smoke sensors with a temperature differential system and a thermal sensor are installed in the entire building. A flame detector is located on the observation tower. Stable fire extinguishing equipment (SFEE) for volume and local fire extinguishing was placed in the building (Otrusina, 2017).

In the dining room as the most valuable room (Fig. 3), EFAS is installed with double suction for smoke detection. In the event of a fire, its protection is ensured by gas extinguishing, due to the complex division of the ceiling structure, the unique appearance of the dining room interior and its equipment. Gas stable fire extinguishers use a mixture of gases INERGEN as an extinguishing agent. It is a mixture of nitrogen 52%, argon 40% and carbon dioxide 8% (Otrusina, 2017). The extinguishing effect is achieved by reducing the oxygen content in the protected room to less than 15%, thereby extinguishing the fire. The gas supply, as well as all technical equipment, including the generator, transformer station, and technical room, is located in Pustevenka (Fig. 3a, b).

Here it is necessary to mention that in the process of designing the layout of SFEE and fire alarm, there was also a requirement not to disturb the aesthetic impression of the room, it means to be seen by firefighters and not by visitors (Masák, 2019).



(a)



(b)

Fig. 3 (a) The Libušín areal: A) dining room with lookout tower, B) neck, C) pub, D) Parma extension, E) Pustevenka, F) kitchen; (b) Design of SFEE layout and fire alarm system in BIM (Masák & Partner, s.r.o., 2021).

As mentioned above, transparent fire glass 4 cm thick was placed on the coffered ceilings (Fig. 4).

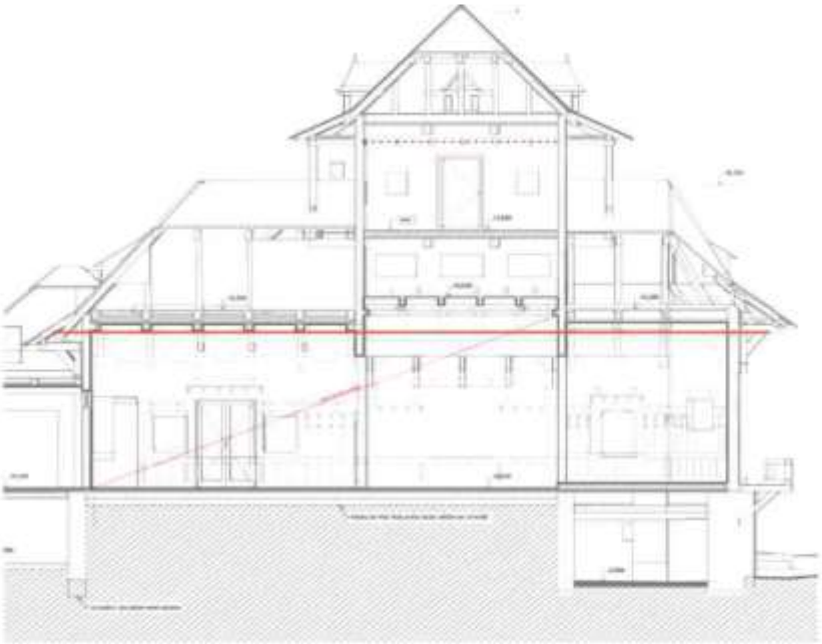


Fig. 4 Location of fire glass (red line) as protection of coffered ceiling (Masák, 2019).

It is a demanding and at the same time unique way of solving fire protection of buildings, which is used in server rooms, computer centres, electrical substations, in warehouses of hazardous and rare substances, but also in museum archives and expositions with archives and everywhere where it is not possible to extinguish with foam or water. This type of extinguishing is activated automatically by EFAS, detectors, but also manually. However, it requires hermetic sealing of the room and gas-tightness of the walls, so that during extinguishing the extinguishing gas does not leak into the outside environment and that the extinguishing concentration is maintained for 10 minutes. For this reason, a special vapor barrier reinforced with a mesh and provided with aluminium foil was inserted under the plaster (Fig. 2b). When using an air conditioner, the EFAS system stops the air exchange in the room. The door has automatic closing controlled by EFAS. Window closing is also connected to the EFAS system. The tiled stove door is also gas-tight.

In the interior of other parts of the building are built-in sprinkler SFEE, where the extinguishing agent is water (Otrusina, 2017). Sprinklers are activated autonomously, selectively, always those that are heated to the so-called opening temperature. In the ceiling of the pub, sprinkler SFEE with retractable heads are used, which have the advantage that they do not interfere visually, as they are hidden under plastic covers in the color of the ceiling and are extended by the water pressure when activated.

On the outside of the roof cladding, there are also built-in SFEE sprays with fixed heads that form a water mist. The extinguishing effect is based on the rapid evaporation and absorption of the heat of the fire by small drops of water mist. This provides total cooling of the protected object. On the side of Maměnka, it is supplemented by a sensor that reacts to a possible fire by Maměnka and starts sprinkling Libušín (Otrusina, 2017).

An underground tank with a volume of 200 m^3 was built in front of the building as a fire water tank. The whole building is secured by voice announcement and alarm sirens. All EFAS sensors are connected to the Central Protection Desk of Fire Rescue Service of Zlín region.

All extinguishing technologies, including electrical installations, are centralized in Pustevenka, from where the distribution lines lead through underground collectors to Libušín (Fig. 3b). The protection of this building is ensured by gas extinguishing. The technologies in the building are so complex that constant checks of their operability will be performed; some will be done once every six months and others even daily.

A similar integration of modern fire-fighting technologies based on extinguishing with a special inert gas occurs in the all-wood Orthodox Church of St. Nicholas in Hradec Králové (transported from Malá Polana from Slovakia in 1935), where there are rare murals on the log walls (Kostel sv. Mikuláše, 2020).

Low-pressure water mist is used for the external protection of listed buildings, such as all-wood churches in Norway and Poland. Of course, they are equipped with EFAS and many of them are connected to the workplaces of the fire brigade. They form a unified system of fire protection and security against theft, burglary and vandalism. The buildings are also equipped with motion sensors and camera systems as well as cameras with thermal imaging. The camera system, including other systems, is installed in indoor and outdoor areas on monuments, but also on columns in the vicinity of the monument. Churches are often located in places where there is not enough fire water, so large fire tanks or non-flooded fire pipes have been built near them in combination with smaller fire tanks, which will be used in the intervention of firefighters. The given technologies are controlled from technical rooms, which are built into the ground near the buildings (Palotová, 2018).

It is exemplary how protected monuments are in Norway, Poland and the Czech Republic, and what sophisticated fire protection solutions these buildings use to preserve them.

4 Conclusions

After the successful renovation of the Libušín building, which was destroyed by fire, and which was one of the largest and most important reconstructions of this type in the Czech Republic, we can say that the integration of modern technology into historic buildings is possible while maintaining their historic character. The newly built Libušín is in all respects closer to the Libušín, which the architect Jurkovič, our Poet of Wood, originally wanted to preserve here, than the one that was here before it burned down.

The modern technologies used do not deprive this building of its unique atmosphere; on the contrary, they are a great contribution to the fact that we can enjoy this atmosphere for future periods.

Thanks to what happened, other wooden buildings are gradually being equipped with fire-fighting elements. In this area we can observe a shift for the better and the figurative spark (impulse) continues.

Acknowledgments

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