ACOUSTIC AND THERMOPHYSICAL PROPERTIES OF RECYCLED MATERIALS BASED ON NEWSPRINT

[a)]Rastislav Igaz, [a)]Miroslav Němec, [b)]Miloš Gejdoš, [a)]Samuel Kočuta, [a)]Dagmara Bednárová

[a)]Technical University in Zvolen, Faculty of Wood Sciences and Technology, Department of Physics, Electrical Engineering and Applied Mechanics, Zvolen, Slovakia, igaz@tuzvo.sk; nemec@tuzvo.sk; samuel.kocuta@gmail.com; bednarova.dagmara@gmail.com

[b)]Technical University in Zvolen, Faculty of Forestry, Department of Forest Harvesting, Logistics and Ameliorations, Zvolen, Slovakia, gejdos@tuzvo.sk

Abstract: The paper deals with the acoustic and thermophysical properties of selected materials created from the recycling of newsprints with potential applications in the structural components of timber buildings. The samples for the study were produced by recycling paper in three forms: as pure paper, then with the addition of used coffee grounds, and then with the addition of rubber from crushed automotive tires. Based on the measurement of the Sound Absorption Coefficient (SAC) and Noise Reduction Coefficient (NRC), it can be concluded that these materials are among the less absorptive in terms of acoustics. The best results were achieved by the material made from newspaper mixed with coffee grounds (NRC is equal to 0.30), which can be classified into sound absorption class D. The other studied materials fall into class E, with an NRC of 0.20. From the perspective of thermophysical properties, the tested materials exhibit thermal conductivity coefficient values ranging from 0.083 to 0.103 $W \cdot m^{-1} \cdot K^{-1}$, indicating that they do not meet the thermal insulation properties commonly associated with standard insulating materials.

Keywords: Sound Absorption Coefficient, Noise Reduction Coefficient, Thermophysical properties, Thermal conductivity coefficient

1. INTRODUCTION

Currently, waste production poses a significant environmental problem, which, according to national statistics, has been steadily rising [1]. There are two approaches to address this issue. The first is a comprehensive reduction in consumption by the population, resulting in decreased waste production. The second involves the recycling of raw materials. However, recycling and waste recovery account for approximately only 38% of the total waste volume, although this figure is gradually increasing at the expense of landfilling. In the case of paper, the recycling rate in Slovakia reaches as high as 75% [1]. Materials made from recycled sources represent a more environmentally sustainable alternative to traditional materials and serve as a tool for waste reduction. The construction sector offers the greatest potential within the national economy for the utilization of waste [2], where recycled insulation materials are becoming a key element in designing energy-efficient and sustainable buildings.

Insulation building materials are part of a crucial technology that reduces energy consumption in buildings by preventing thermal flow through the envelope construction, while also achieving a pleasant and healthy internal climate throughout the year. Thermal insulation materials are produced from various types of materials and in different physical forms for use in specific building constructions [3]. Increased attention has been paid in recent years to the research of recycled and natural materials that have the potential to develop eco-friendly, environmentally sustainable, and locally available insulation materials.

From the perspective of sustainable development, it is essential to focus on materials that are easily recyclable, renewable, locally available, and environmentally friendly. Considering the cost-effective, biodegradable, durable, and enviro-friendly construction materials, there is a need to meet global thermal protection demands through these appealing properties. The low thermal conductivity and fibrous structure of most organic materials significantly enhance thermal insulation performance once integrated into the external envelope of buildings. Natural organic materials exhibit higher specific heat capacity and greater sensitivity to moisture, which are advantageous physical properties compared to conventional silicate materials [4].

In addition to thermophysical properties, acoustic properties are also critical when assessing insulation materials. To ensure acoustic comfort for users, addressing noise must occur in the initial design phase of buildings. The first step towards meeting acoustic requirements is the appropriate positioning of the building according to its intended use. Sound-absorbing materials are typically either fibrous or porous. These cavities allow for airflow, during which acoustic energy transforms into thermal energy within this diffusion field. At low frequencies, an isothermal process occurs, whereas at high frequencies, an adiabatic process takes place [5].

This study focuses on the research and analysis of the acoustic and thermophysical properties of recycled materials based on newsprints with various additives, holding potential for further use in timber construction structures. The long-term aim is to identify suitable recycled materials that contribute to environmental protection while also providing the necessary insulation properties for modern buildings.

2. MATERIAL AND METHODS

2. 1. Sample preparation

In the experimental research, three types of materials were tested. The first material consisted solely of pure newsprint, the second was created from a mixture of newsprint and used coffee grounds from a coffee maker (20% coffee grounds and 80% newsprint). The third type was formed by adding rubber granulate from automobile tires (15% share) to newsprint (85% share).

All three materials were prepared using a similar procedure. The dry, unwaxed newsprint was torn and subsequently soaked in clean water for 24 hours. After soaking and the potential addition of additives (coffee, rubber), the mixture was manually stirred, poured, and hand-pressed into prepared molds made from cut plastic waste tubes (see Fig. 1). Four samples of each type of material were created. The samples were naturally dried for 5 days to achieve initial stiffness. In the next step, the samples were dried in an oven at a temperature of 103 °C ± 2 °C until they reached a constant weight. After drying, they were acclimatized for the next 3 weeks at room temperature and humidity. Finally, the samples were shaped to the required dimensions needed for further measurements. The resulting steady-state moisture content of the samples (w) after acclimatization was determined gravimetrically, and the bulk density (ρ) was also measured after acclimatization. The values for each type of material are presented in Tab. 1.

2. 2. Measurement of Sound Absorption Coefficient

The Sound Absorption Coefficient (SAC) of all samples was measured according to EN ISO 10534-2: Determination of sound absorption coefficient and impedance in impedance tubes - Part 2: Transfer function method [6]. A Kundt's tube, Brüel & Kjær 4206, with accessories (system PULSE 14, signal generator, 2 microphones, LAN-XI module Brüel & Kjær type 3050, computer – Fig. 2) (Brüel & Kjær, an HBK company, Nærum, Denmark) was used for the measurement. Pink noise was employed as the input signal, which was captured by two microphones in the tube, and based on the response, the frequency dependence of the sound absorption coefficient was determined. The samples for this measurement were shaped into cylinders with a thickness of 10 mm and a diameter of 99 mm for measurements in the frequency range up to 1.6 kHz. The diameter of these samples for measuring SAC up to 6.4 kHz was 29 mm. The resulting graphical frequency dependence of SAC was determined by averaging four measurements for each material.

In addition to the frequency dependence of SAC, the Noise Reduction Coefficient (NRC) was also calculated for each material, which is defined as the arithmetic mean of SAC at frequencies of 250 Hz, 500 Hz, 1000 Hz, and 2000 Hz rounded to the nearest 0.05.

Fig. 1: Samples prepared for drying

2. 3. Measurement of thermophysical properties

To determine the thermophysical properties of materials, the Hot Disc TPS 2500s device (Hot Disc AB, Göteborg, Sweden) was employed, utilizing the Transient Plane Source (TPS) method. This method allows for the simultaneous determination of the thermal conductivity coefficient λ, the thermal diffusivity α, and the volumetric heat capacity cV of a wide range of materials (solids, pastes, powders) across an extensive range of values. Based on the known density, it is then possible to establish the specific heat capacity cm. The method is absolute, eliminating the need for calibration, and also standardized in ISO 22007-2. The sensor consists of a dual-layer spiral made of nickel, coated with a thin layer of insulating material (25 µm), which is placed between two flat samples of the material under investigation. The sensor is electrically connected to a power supply and measurement circuit. During the measurement, a constant electric current is supplied to the sensor, which converts the electric energy into heat. This generated heat is conducted into the sample material, with the rate of heat

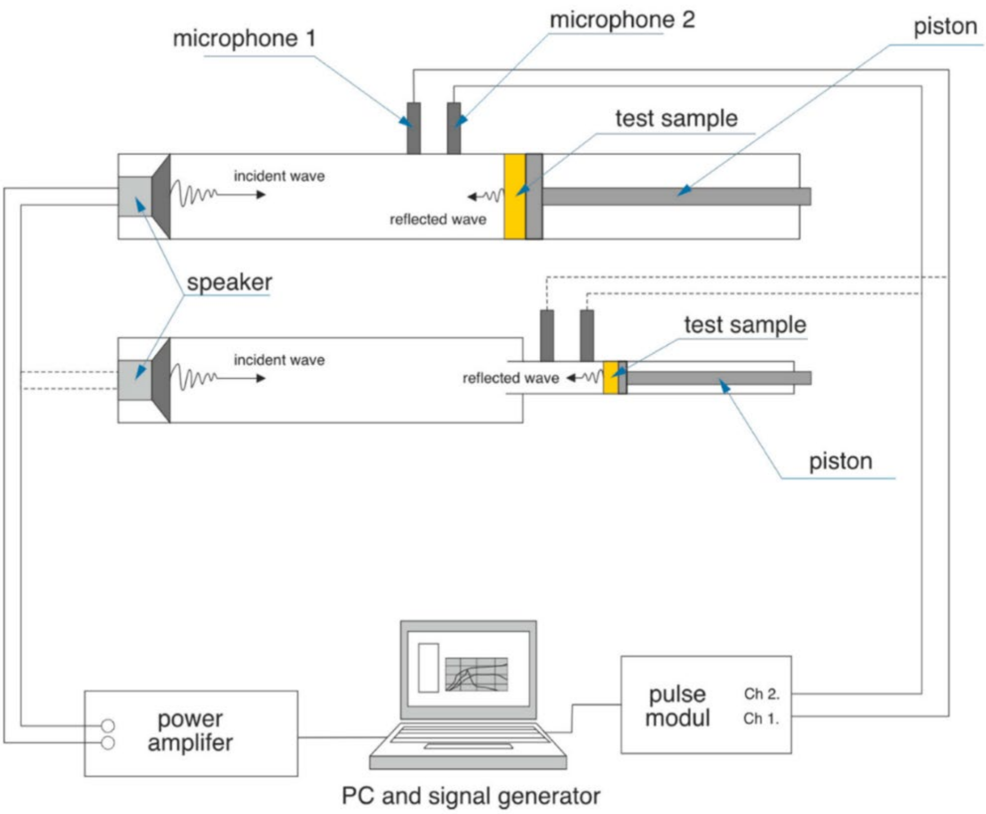

Fig. 2: Schematic diagram of the impedance tube connection

transfer depending on the thermophysical characteristics of the material. Simultaneously, the sensor serves as a temperature detector, where the change in temperature is directly proportional to the change in the electrical resistance of the sensor. By analysing the recorded temporal change in temperature, the thermophysical characteristics of the tested material are determined based on the model.

Before measurement, the samples were abraded on a cylindrical grinder to achieve a flat surface necessary for optimal contact with the sensor. Pairs of samples were prepared for measurement (as required by the method), and measurements were conducted on each pair. Five repeated measurements were performed on each pair, always in a different area of the sample. This procedure yielded 10 values of thermophysical characteristics for each type of material.

3. RESULTS AND DISCUSSION

3. 1. Material properties

The material samples were prepared according to the methodology outlined above. Prior to testing the samples, the equilibrium moisture content w was established after conditioning, along with the bulk density ρ of the materials. As shown in the results in Tab. 1, the moisture content of the samples stabilized at different values. In the case of pure paper and paper with added coffee, the absorption moisture content stabilized at 6.2 %. For the samples containing crushed rubber, the moisture content stabilized at 4.4 %. This phenomenon is likely attributed to the presence of rubber, which constitutes 15 % of the sample volume, as rubber is inert to the absorption of atmospheric moisture.

From the perspective of bulk density, it is evident that pure paper exhibits the lowest value. The addition of the coffee blend results in an increase in bulk density, which is due to the higher density of the ground coffee mixture. The greater variability in density is likely a consequence of the sample preparation technology. The highest density among the samples was determined for the paper with added crushed rubber. This increase is primarily attributed to the density of the rubber additive.

Material	w (%)	ρ (kg.m^{-3})
paper	6.28±0.05	214.3±6.1
paper + coffee	6.21±0.03	251.7±34.5
paper + rubber	4.43±0.04	327.3±28.7

Tab. 1: Equilibrium sorption moisture and density of samples after conditioning

3. 2. Sound absorption coefficient

Fig 3. provides a graphical representation of the frequency dependence of the sound absorption coefficient for the examined materials. At first glance, it is clear that the paper mixed with coffee demonstrates significantly better absorption in the frequency range between 1 kHz and 4 kHz compared to the other two materials. In the remaining frequency ranges, the differences among the materials are relatively insignificant. The maximum SAC value of 0.61 is achieved by this material at approximately 2.3 kHz. Pure paper reaches a maximum SAC of 0.34 at a frequency around 930 Hz, while the paper mixed with rubber has a maximum SAC value of 0.31 at approximately 850 Hz.

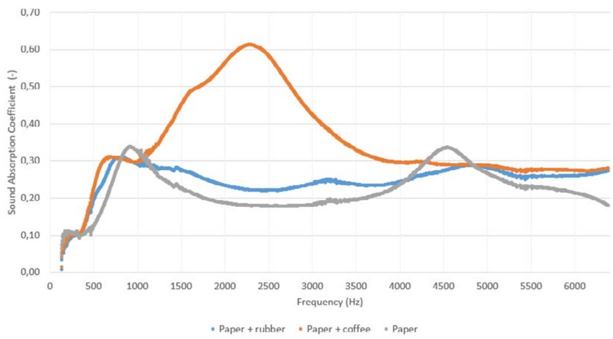

Fig. 3: Frequency dependence of the sound absorption coefficient of the examined materials

The Noise Reduction Coefficient (NRC) values for the individual materials are, as expected, quite low. The NRC for pure paper and paper with added rubber is 0.20. In terms of sound absorption classification, these materials fall into class E. The paper with waste coffee blend achieved a better sound absorption value in the mid-frequency range, which is reflected in the NRC value of 0.30, categorizing it into sound absorption class D. The measurement results show similarities with the results of sound absorption measurements on board construction materials used in wooden buildings [18].

Many other natural-based materials exhibit similar SAC values to those studied by us. According to a study by [7], larch bark panels were classified as sound absorbing class E, with an NRC value of 0.20. Similar results were observed in a study by [8] with samples of concrete containing corn cobs, sunflower stalks, and sheep wool granules, where NRC values were also around 0.20. The study by [9]. indicated that samples made from banana peels, grass, lemongrass, and palm leaves attained NRC values ranging from 0.10 to 0.15, categorizing them into sound absorption class E. Excellent absorption (NRC in the range of 0.75 to 0.90) was achieved by the latex and jute felt samples studied by [10]. Based on these values, they were classified into sound absorption classes B and C.

The results suggest that the materials examined are not suitable for application as sound-absorbing materials. The samples containing used coffee fall into class D, while those with crushed rubber fall into class E. The reason for these results is the method of sample production using the wet process, where, after soaking, the materials were pressed into molds. This procedure resulted in a higher density of the materials but simultaneously eliminated the porous structure responsible for good air absorption capability.

3. 3. Thermophysical properties

The results of the determination of thermophysical properties of the tested samples based on recycled paper are summarized in Tab. 2. The measurement was conducted after conditioning in stable conditions. The employed method falls within the category of non-stationary techniques, where the measurements typically last only a few minutes. An advantage of this methodology is that it does not require the establishment of a stationary temperature field, which, in the case of similar materials, can lead to sample desiccation, consequently reducing thermal conductivity and specific heat capacity.

Material	λ ($W \cdot m^{-1} \cdot K^{-1}$)	c_m ($J.kg^{-1}.K^{-1}$)
paper	0.083±0.001	1109.8±61.0
paper + coffee	0.101±0.001	1553.7±55.6
paper + rubber	0.103±0.001	1123.8±58.1

Tab. 2: Thermal conductivity coefficient λ and specific heat capacity cm of samples

As indicated by the results, the samples prepared from pure paper exhibit the lowest thermal conductivity coefficient. Additionally, these samples also demonstrate the lowest specific heat capacity. This phenomenon is correlated with the bulk density of the material. Generally, the thermal conductivity of materials significantly correlates with their density [11, 12]. In samples containing additives of coffee and rubber, the thermal conductivity increases by approximately 23%. In the case of coffee addition, this increase can be attributed to the rise in density and the relatively high thermal conductivity of coffee grounds (0.18 $W \cdot m^{-1} \cdot K^{-1}$), which are dispersed in the paper matrix as fine powder particles. However, when rubber is added, although there is a significant increase in density, the rubber itself has low thermal conductivity (λ = 0.16 $W \cdot m^{-1} \cdot K^{-1}$), resulting in a minimal contribution to the overall thermal conductivity increase of the paper-rubber mixture. Similarly, the specific heat capacity of the rubber additive (c_m = 1100 $J \cdot kg^{-1} \cdot K^{-1}$) is relatively low and, therefore, does not significantly enhance the thermal capacity of the composite.

In comparison to other materials made from natural fibrous substances, the tested samples exhibit higher values of thermal conductivity. For instance, materials prepared from cane fibers achieve a thermal conductivity coefficient of λ = 0.045 – 0.056 $W \cdot m^{-1} \cdot K^{-1}$ at a density of 130 – 190 $kg \cdot m^{-3}$, materials from rice husks have λ = 0.046 – 0.057 $W \cdot m^{-1} \cdot K^{-1}$ at a density of 154 $kg \cdot m^{-3}$, or materials from straw reach a value of λ = 0.067 $W \cdot m^{-1} \cdot K^{-1}$ at a density of 60 $kg \cdot m^{-3}$ [13]. Products made of recycled materials are characterized by better thermal insulation performance compared to the natural ones. Material made of recycled PET have thermal conductivity about 0,036 $W \cdot m^{-1} \cdot K^{-1}$ (14). Material made of recycled glass has a thermal conductivity and specific heat values similar to rockwool (15) or recycled textile materials are characterized by low thermal conductivity and their insulation performance can be compared to the expanded and extruded polystyrene (16, 17). Commercially produced insulation materials such as polystyrene, polyurethane, glass or rock wool typically achieve values lower than 0.04 $W \cdot m^{-1} \cdot K^{-1}$ (13).

Further research will adjust the material manufacturing process with the goal of achieving a lower target density. This adjustment will lead to a reduction in the thermal conductivity coefficient, and the prepared material will thus be closer in its thermophysical properties to materials with greater application potential.

4. CONCLUSION

The study evaluated the acoustic and thermophysical properties of recycled paper-based materials. The results suggest that the samples we investigated possess lower sound absorption capabilities and exhibit relatively higher thermal conductivity compared to conventional insulation materials. These characteristics limit their potential use as thermal insulation and sound-absorbing materials in construction. However, these recycled materials have potential applications in enhancing the acoustic properties of building structures or as components of multilayer insulation systems, where they might complement or partially replace other insulation materials.

By employing alternative manufacturing technology, improved properties could be achieved (such as with blown cellulose, which is a similar material). The next research step will involve the optimization of the manufacturing processes for these recycled materials to enhance their acoustic and thermal insulation properties. Furthermore, it will be necessary to investigate these materials from the perspective of their environmental impacts.

5. ACKNOWLEDGEMENT

This research was funded by the Slovak Research and Development Agency (Grant Numbers APVV-22-0001 and APVV-23-0369) and Ministry of Education, Science, Research and Sport of the Slovak Republic (Grant Number VEGA 1/0179/25, KEGA 004TU Z-4/2023 and KEGA 003TU Z-4/2024)

REFERENCES

[1] Správa o stave životného prostredia Slovenskej republiky v roku 2018 (Rozšírené hodnotenie kvality a starostlivosti). 2018. Available from: https://www.enviroportal.sk/spravy/detail/10261?p=9341

[2] Orlik-Kozdon, B. Assessment of the application efficiency of recycling materials in thermal insulations. Construction and Building Materials [online]. 2017, Vol. 156, p. 476–485. ISSN 0950-0618. https://www.doi.org/10.1016/j.conbuildmat.2017.08.134

[3] H. Pifko: Alternative Building Materials and Technologies. Život. Prostr., Vol. 38, No. 4, p. 188 – 193, 2004.

[4] Dikmen, N., Ozkan, S. T. E. 2016. Unconventional Insulation Materials. V: A. ALMUSAED a A. ALMSSAD, ed. [online]. B.m.: InTech [cit. 22.5.2024]. ISBN 978-953-51-2624-9. https://doi.org/10.5772/63311

[5] Bertolini, M. D. S., De Morais C. A. G., Christoforo, A. L., Bertoli, S. R., Dos Santos, W. N., Lahr F. A. R. Acoustic absorption and thermal insulation of wood panels: Influence of porosity. BioResources [online]. 2019, Vol. 14, No. 2, p. 3746–3757. ISSN 19302126, 19302126. https://www.doi.org/10.15376/biores.14.2.3746-3757

[6] EN ISO 10534-2. Acoustics—Determination of Sound Absorption Coefficient and Impedance in Impedance Tubes—Part 2: Transfer-FunctionMethod; European Committee for

Standardization (CEN): Brüssel, Belgium, 2002. (PDF) Acoustic Properties of Larch Bark Panels. Available from: https://www.researchgate.net/publication/353014036_Acoustic_Properties_of_Larch_Bark_Panels [accessed Nov 20 2024].

[7] Tudor, E.M.; Kristak, L.; Barbu, M.C.; Gergeľ, T.; Němec, M.; Kain, G.; Réh, R. Acoustic Properties of Larch Bark Panels. Forests 2021, Vol. 12, No. 887. doi.org/10.3390/f12070887

[8] Oancea, I., Bujoreanu, C., Budescu, M., Benchea, M., Gradinaru C. Considerations on sound absorption coefficient of sustainable concrete with different waste replacements. Journal of Cleaner Production [online]. 2018, Vol. 203, p. 301–312. ISSN 0959-6526. https://doi.org/10.1016/j.jclepro.2018.08.273

[9] Shahid NSM., Ahmad MA., Tahir FLM. Sound Absorption Coefficient of Different Green Materials Polymer on Noise Reduction. 2020. International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075 (Online), Volume-9 Issue-3,

[10] Fatima, S., Mohanty, A. R. MOHANTY. Acoustical and fire-retardant properties of jute composite materials. Applied Acoustics [online]. 2011, Vol. 72, č. 2, s. 108–114. ISSN 0003-682X. https://doi.org/10.1016/j.apacoust.2010.10.005

[11] Krišťák, Ľ., Igaz, R., Ružiak, I. Applying the EDPS method to the research into thermophysical properties of solid wood of coniferous trees. In: Advances in materials science and engineering. 2019, ISSN 1687-8434. https://doi.org/10.1155/2019/2303720

[12] Igaz, R., Krišťák, Ľ., Ružiak, I., Gajtanska, M., Kučerka, M. Thermophysical properties of OSB boards versus equilibrium moisture content. In: BioResources. 2017. Vol.. 12, No. 4, p. 8106--8118. ISSN 1930-2126. https://doi.org/10.15376/biores.12.4.8106-8118

[13] Asdrubali, F., D´Alessandro, F., Schiavoni, S. A review of unconventional sustainable buildings insulation materials. Sustainable Materials and Technologies. 2015. Vol. 4.,p. 1 – 17. doi: 10.1016/j.susmat.2015.05.002

[14] Intini, F., Kühtz, S. Recycling in buildings: an LCA case study of a thermal insulation panel made of polyester fiber, recycled from post-consumer PET bottles. International Journal of Life Cycle Assessment. 16. 2011. 306-315. https://doi.org/10.1007/s11367-011-0267-9

[15] FOAMGLAS® thermal insulation made of cellular glass [online]. Pittsburgh Corning EUROPE N.V., Tessenderlo, B, 2025. Available on internet: https://www.foamglas.com/en/

[16] Briga-Sá. A., Nascimento. D., Teixeira, N., Pinto, J., Caldeira, F., Varum, H., Paiva, A. Textile waste as an alternative thermal insulation building material solution. Construction and Building Materials 38. 2013. 155–160, https://doi.org/10.1016/j.conbuildmat.2012.08.037

[17] Ricciardi, P., Belloni, E., Cotana, F. Innovative panels with recycled materials: thermal and acoustic performance and life cycle assessment. Applied Energy 134. 2014. 150-162. doi.org/10.1016/j.apenergy.2014.07.112

[18] Čulík, Martin, Anna Danihelová, Vojtěch Ondrejka a Patrik Aláč. Sound absorption of board construction materials used in wooden buildings. Akustika: odborný časopis o akustice a vibracích. 2020, 37(prosinec), 52-58. ISSN 1801-9064.

Rastislav Igaz

was born in April 1977. He is working as a assistent professor at the Department of Physics, Electrical Engineering and Applied Mechanics of the Faculty of Woodsciences and Technology, Technical University in Zvolen. PhD study ended with the defense of work focused to heat transfer research using holographic interferometry. His pedagogical activities is focused on the areas related to heat and mass transfer, building physics and metrology. In research area he currently focused into the thermophysical properties of wood and wood-based materials, heat transfer in wood processing and heat transfer in production technologies of wood based composites.

Samuel Kočuta

is a student at the Faculty of Wood Sciences and Technology in the study program Timber and Wood Structures. For his thesis, he focused on research on insulating materials based on recycled paper and the study of their thermophysical and acoustic properties.

Miroslav Němec

He is working as Associated professor in specialization „Acoustic" and „Theory of Education of Physics" at Department of Physics, Electrical Engineering and Applied Mechanics at the Faculty of Wood Sciences and Technology at Technical University in Zvolen. He specializes in research in fields of building acoustic, environmental noise and theory of education of physics. Each year he organizes an international conference with colleagues „Material-Acoustic-Place" in Zvolen (SK). He is a full member of the Slovak Acoustical Society and of the European Acoustic Association.

Miloš Gejdoš

Working as Associated professor in specialization „Forestry technique and wood processing" at the Department of Forest Harvesting, Logistics and Ameliorations at the Faculty of Forestry at the Technical University in Zvolen and as a Researcher at the National Forest Centre in Zvolen. He specializes in research of wood quality, raw-wood assortments assessment and development the market with wood. He is a member of the Slovak Acoustical Society and a full member of the European Acoustics Association.

Dagmara Bednárová

holds both a bachelor's and a master's degree in Environmental Engineering from the Faculty of Ecology and Environmental Sciences at the Technical University in Zvolen. She is currently a second-year PhD. student at the same faculty, continuing her research on physical factors in the working environment, with a focus on noise and dust pollution.