World Academy of Science, Engineering and Technology
International Journal of Civil and Environmental Engineering
Vol:18, No:4, 2024

Investigation of the Acoustic Properties of Recycled Felt Panels and Their Application in Classrooms and Multi-Purpose Halls

Ivanova B. Natalia, Djambova T. Svetlana, Hristev S. Ivailo

***Abstract*—**The acoustic properties of recycled felt panels have been investigated using various methods. Experimentally, the sound insulation of the panels has been evaluated for frequencies in the range of 600 Hz to 4000 Hz, utilizing a small-sized acoustic chamber. Additionally, the sound absorption coefficient for the frequency range of 63 Hz to 4000 Hz was measured according to the EN ISO 354 standard in a laboratory reverberation room. This research was deemed necessary after conducting reverberation time measurements of a university classroom following the EN ISO 3382-2 standard. The measurements indicated values of 2.86 s at 500 Hz, 3.23 s at 1000 Hz, and 2.53 s at 2000 Hz, which significantly exceeded the requirements set by the national regulatory framework (0.6 s) for such premises. For this reason, recycled felt panels have been investigated in the laboratory, showing very good acoustic properties at high frequencies. To enhance performance in the low frequencies, the influence of the distance of the panel spacing was examined. Furthermore, the sound insulation of the panels was studied to expand the possibilities of their application, both for the acoustic treatment of educational and multifunctional halls and for sound insulation purposes (e.g., a suspended ceiling with an air gap passing from room to room). As a conclusion, a theoretical acoustic design of the classroom has been carried out with suggestions for improvements to achieve the necessary acoustic and aesthetic parameters for such rooms.

***Keywords*—**Acoustic panels, recycled felt, sound absorption, sound insulation, classroom acoustics.

I. Introduction

THE purpose of this study and subsequent series by the team is to enhance the interest in recycled materials and explore their greater applications in construction. The subject of this investigation is recycled polyester felt, which allows for easy processing and possesses good aesthetic and physical qualities.

The research is directed towards improving the acoustic quality of educational spaces. It is well-known that suitable acoustics improve the learning process and enhance students' perception. Moreover, the physical and mental well-being of all participants in the educational process is of utmost importance. Sound is perceived very personally, and our forthcoming study on students of different ages reveals that age also plays a role in assessing the quality of the environment, including acoustic preferences (such as reverberant or dead rooms). Increasing the area of sound-absorbing materials is a trend that often indicates a positive impact. The aim is to achieve a reverberation time in classrooms and educational halls around 0.6 to 1.2 seconds. This range provides sufficient speech clarity while reducing unwanted echoes and reflections.

Different national regulations set values based on the purpose and volume of the room. For instance, DIN 18041 [1] and ÖNORM B 8115-3 [2] require lower reverberation times for the high and low-frequency range, while Italian UNI 11532 [3] has a different approach. In Bulgaria, national requirements define maximum values for three frequencies. The acoustic treatment in this work aligns with the requirements of the HQE (Haute Qualité Environnementale) schools, as they can be considered internationally significant.

Sound plays a vital role in our lives, as it has been present since birth. It is an inherent characteristic of existence, and everything we do in the name of life confirms its importance. Among the five senses granted to explore the world, hearing is one of the primary ones, through which we perceive messages, changes in weather, and our sense of the world. Over time, sound serves as a tool for orientation, reactions, emotions, and expressing one's personality. It acts at a distance through sound waves, and the body reacts, amplifying feelings of fear, euphoria, joy, pain, irritation, and restlessness. It can either stimulate or hinder the learning process, influencing emotional well-being and inspiration. Sound should be a positive influence on people, encouraging the creative process. Though the laws of sound propagation are studied, there remain unknown and indescribable spheres. For example, one church sounds precisely like a church, even though it has the same reverberation time as any other space. In a closed environment, sound can manifest itself with force, power, finesse, dynamic nuances, and timbre. Studying sound in any form contributes to expanding and enriching our understanding, taming it, and channeling it positively towards the good.

At the same time, due to haste and the emergence of other priorities, neglect has been observed, particularly in the field of room acoustics in Bulgaria. The team of this article conducted measurements in several classrooms, and especially the newly renovated ones showed significant deviations from the requirements. For example, one of the classrooms exhibited the following measurement results: 2.86 s at 500 Hz; 3.23 s at 1000

N. B. Ivanova is with University of Architecture, Civil Engineering and Geodesy /UACEG/, Physics Department, Hr.Smirnenski Blvd. 1, 1164 Sofia, Bulgaria (corresponding author, phone: 00359-889-220170; e-mail: bobeva_fhe@@uacg.bg).

S. T. Djambova is with University of Architecture, Civil Engineering and Geodesy /UACEG/, Physics Department, Hr.Smirnenski Blvd. 1, 1164 Sofia, Bulgaria (e-mail: std_fhe@uacg.bg).

I.S.Hristev is with University of Architecture, Civil Engineering and Geodesy, Residential Buildings Department, Hr.Smirnenski Blvd. 1, 1164 Sofia, Bulgaria (e-mail: office@stivox.com).

Hz, and 2.53 s at 2000 Hz. These values far exceed the regulations [4], necessitating acoustic treatment. This led us to explore recycled materials and propose a suitable improvement option without the need for floor replacement.

In Bulgaria, in the University of Architecture, Civil Engineering and Geodesy /UACEG/ has been formed a team dedicated to acoustics, developing laboratory setups such as a small size acoustic chamber and a reverberation chamber. Collaborating with other specialists, they comprehensively and polyphonically investigate the various effects of applied constructions for optimization. The ecological factor is also considered, utilizing recycled materials, exploring their utility and proper application.

There is even an idea to establish an acoustic center in a region with a mixed population in the Rhodope Mountains. By utilizing the suitable acoustic environment and the serene and inspiring natural atmosphere of the location, the center could contribute to the spiritualization of sound matter. The important thing is to have the aspiration to delve deeper into the incomprehensible realms and discover the root cause of processes. Dreams become conduits for situations that eventually materialize into reality. Scientific discoveries harness humanity's need to understand the world around them and make use of what is available. However, humans change, and what was relevant a hundred years ago is now mere history. Scientists uncover the changes in the senses and what the modern human requires. Orientation is transformed not only by technology but also technology itself is part of this process of change. Therefore, it is essential to continually maintain this catalyst for science and innovation.

II. Investigation

A. Research Topic

The research topic revolves around felt panels made from recyclable, formable polyester fiber and wool. Exceptional acoustic properties of the panels improve speech intelligibility and reduce acoustic reverberation.

Smart array of shapes and sizes allows the control of room acoustics, along with custom design of the patterns to meet the aesthetic needs of any interior design. This panel can be customized in size, thickness, shape, patterns and colors to elevate both acoustic and visual appearance of any space.

The technical data for the material are provided in Table I.

TABLE I
TECHNICAL CHARACTERISTICS

	Unit	Value
Thickness	mm	12
Dimensions per sheets	mm	1480x3000
Density	gr/m^2	2200
Material		100% Polyester (65% Recycled)
Color		Available in RAL color
Fire class		B-s1,d0

The thickness used for these panels is 12 mm, and both their sound absorption and sound insulation properties have been investigated. The sound absorption coefficient was measured in the newly created reverberation room at University of Architecture, Civil Engineering and Geodesy /UACEG/, with measurements also taken on mineral wool for comparison. Sound insulation was measured using the small size acoustic chamber method, which was also developed at UACEG and subject to several years of research leading to numerous publications. This material was chosen due to its demonstrated excellent qualities and the possibility of utilizing it through recycling waste materials, which degrade slowly and are difficult to manage. This contributes to environmental preservation by investing in and utilizing these currently relevant remnants of artificial materials, simultaneously reducing the need for valuable raw materials.

B. Methods of Measurement

Experimentally, with the help of a small size acoustic chamber, the sound insulation of the panels has been evaluated for frequencies in the range of 600 Hz - 4000 Hz [5], [6].

The view of the proposed experimental arrangement to prepare the comparative measurements of sound insulation materials is presented as picture in Fig. 1.

Fig. 1 Small size acoustic chamber

The sound absorption coefficient for the 63 Hz - 4000 Hz frequency range has been measured according to the EN ISO 354 [7] standard in a laboratory reverberation room. Reverberation time was measured in the new reverberation around felt be used to determine the sound absorption coefficient of the investigated object for diffuse sound incidence. In large reverberation rooms, measurements are made according to ISO 354 ($V \geq 150$ m³, here $V = 210$ m^3).

Fig. 2 Reverberation room in UACG according EN ISO 354

The research became necessary after carrying out reverberation time measurements according to the EN ISO 3382-2 [8] standard of a university classroom.

Fig. 3 Photograph of the classroom during measurement of the reverberation time

C. Results

The results of the measurements are presented in graphical formats. The measured sound absorption coefficient by frequencies is presented in Fig. 4, while the sound insulation is shown in Fig. 5.

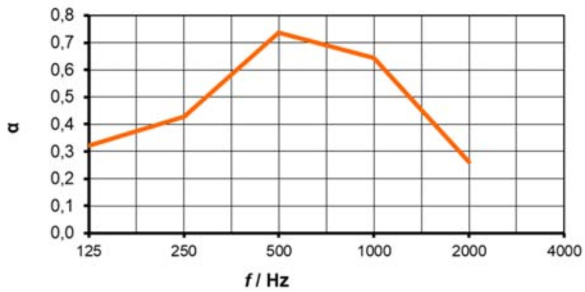

Fig. 4 Sound absorption coefficient of the felt

The sound pressure loss in the sample *D(f)* (Level Difference) in decibels is calculated as the difference between the sound pressure level of the source L_1 *(f)* in dB and the sound pressure level L_2 *(f)* in dB omitted by the sample for each third-octave frequency by (1):

$$D(f) = L_1(f) - L_2(f) \quad (1)$$

L1 - average sound pressure level in the source room, dB; *L2* - average sound pressure level in the receiving room, dB.

The measured sound absorption coefficient was used to calculate the reverberation time. A proposal for acoustic treatment in Classroom shown in Fig. 6 using the researched material was made. To meet the HQE requirements, it was necessary to apply 35 m^2 of this felt on one of the long walls and 5 0m^2 on part of the ceiling, totaling 70 m^2. More information about acoustic treatment through various surfaces is presented in Table II.

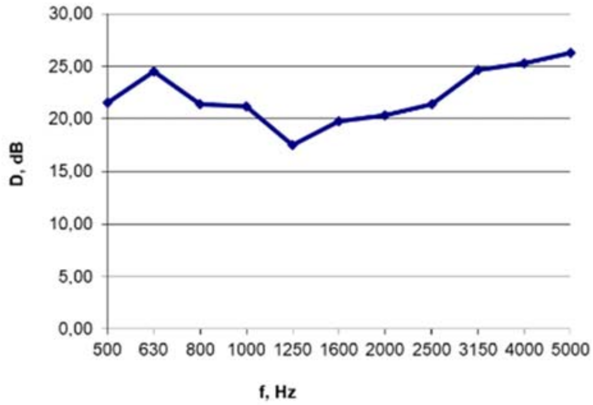

Fig. 5 Sound level difference of felt, measured in the small size chamber

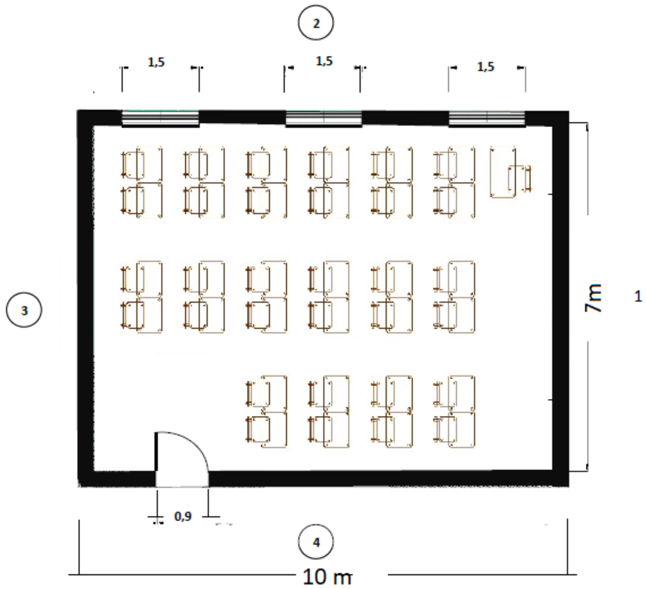

Fig. 6 Floor plan of the classroom

TABLE II
ACOUSTIC SURFACE TREATMENT

Surface	Area, m^2	Type
ceiling	50	felt
ceiling	20	plaster
internal wall 4	35	plaster
adjacent wall 3	25,2	felt
adjacent wall 1	25,2	plaster
blackboard and the wall 1	7	6 cm distance
floor (existing)	70	tiles

The results of the reverberation time calculations are illustrated in Fig. 7.

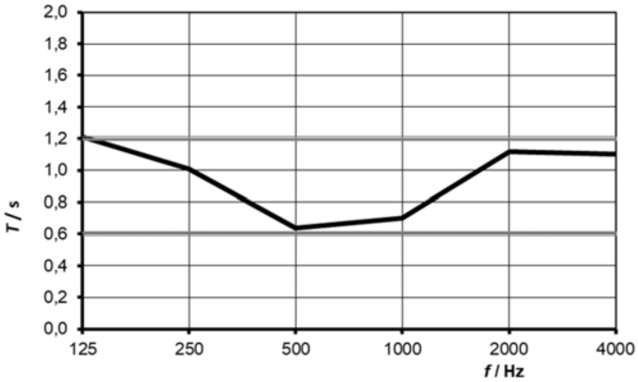

Fig. 7 Reverberation time T/s with acoustic treatment according HQE requirements

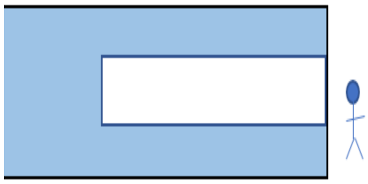

Fig. 8 Position of felt plate (with blue color) on the ceiling

In addition, it is recommended to correctly place the ceiling as shown in Fig. 8. Furthermore, a 6 cm separation between the writing board and the wall is recommended for better sound absorption in the low frequencies.

III. Conclusion

The conducted research is part of a series of measurements in the field of acoustics, sound absorption, and sound insulation, all of which are crucial to meet modern requirements for educational spaces. The topic of acoustics is not sufficiently covered in our educational program and scientific practice, yet it holds significant importance in creating suitable environments for healthy and effective learning processes and improving acoustic comfort in spaces.

On-site measurements undeniably provide the most accurate assessment of the actual situation and decision-making. The results provide guidelines for proper acoustic design and aid in finding broader applications for new, contemporary, and eco-friendly materials. A comprehensive examination of their qualities facilitates their efficient use.

The posed questions highlight the necessity for development in this area, ensuring the proper design of educational spaces, and also for incorporating this subject into the education of architecture and engineering students in the study of Building Physics.

References

[1] DIN 18041 (2016), "Hörsamkeit in Räumen—Anforderungen Empfehlungen und Hinweise für die Planung" ("Acoustic quality in rooms—specifications and instructions for the room acoustic design") (German Institute for Standardisation, Berlin).
[2] ÖNORM B 8115-3: 2005 11 01, "Schallschutz und Raumakustik im Hochbau - Teil 3: Raumakustik."
[3] Arianna A., Linda P., Dario D., Massimo G., "The new Italian standard UNI 11532 on acoustics for schools", *ICA 2019*, Aachen.
[4] Ordinance No. RD-02-20-3 of 21.12.2015 on the design, implementation and maintenance of public service buildings in the fields of education and science, health care, culture and the arts. – in Bulgarian.
[5] S. Djambova, Ts. Nedkov, I. Hristev, "Ability Test of Laboratory Soundproofed Chamber for Evaluation of Building Elements Noise Insulation", *Annual of the University of Architecture, Civil Engineering and Geodesy*, Vol. 49, Issue 4, pp. 141-148, Sofia, 2016, ISSN 2534-9759 – in Bulgarian.
[6] Djambova, S.T., Ivanova, N.B., Pleshkova-Bekiarska, S.G. "Comparative Measurements of Sound Insulation of Materials Placed in Small Size Acoustic Chamber", *57th International Scientific Conference on Information, Communication and Energy Systems and Technologies, ICEST 2022*, Ohrid, North Macedonia. https://ieeexplore.ieee.org/document/9828622
[7] БДС EN ISO 354:2003, "Acoustics — Measurement of sound absorption in a reverberation room".
[8] ISO 3382-2:2008, "Acoustics - Measurement of room acoustic parameters - Part 2: Reverberation time in ordinary rooms".

Natalia B. Ivanova, PhD, Eng. Ph.D. Thesis: *Comparative Study Of Sound Insulation Of Building Elements By Small-Scaled Acoustic Chamber* in University of Architecture, Civil Engineering and Geodesy /UACEG/, Faculty of Structural Engineering, Department of Building Materials and Insulations.
Graduated Building Physics at the University of Applied Science, Stuttgart, Germany. Master in Civil Engineer, UACEG, Sofia, Bulgaria.
With practical experience in the field of acoustic planning, measurement and consulting in Bulgaria and Germany, of acoustic evaluations and recommendations for classrooms, offices and conference rooms in Germany and abroad.

Svetlana T. Djambova, Assoc. Prof., Dr. in Physics, Head of the Physics Department in UACEG, Master Degree in Engineering Physics in Sofia University, Ph.D. and research carrier in the Bulgarian Academy of Sciences – Institute of Solid State Physics. Research fellowship also at University of Virginia, USA and Research Corporation of Virginia – Radford, Virginia.

Ivailo S. Hristev, Acoustic Eng. Graduated Master of Science in Electronics at Sofia Technical University. M.Sc. in Engineering Acoustics at Danish Technical University, Active contributor to all projects. Member of National Technical Union – Acoustics section, Member of Chamber of Engineers. Ph.D. student at Technical University – Sofia. Acoustic company owner.