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Acoustics of a School Building Made in Wooden Technology on the Example of Building from the Second Half of the 19th Century

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Abstract. The Władysław Matlakowski School in Zakopane was established in 1877. After the war damage, during the Communist rule in Poland the school was rebuilt and renovated. As a result, the original character of the classrooms was distorted. Fiberboards used for interior finishing changed the acoustic climate of the rooms. The reverberation time of the tested rooms considerably exceeds 2 seconds for low frequencies and is below 2 seconds for medium frequencies. Thus, the reverberation conditions do not differ from typical school classrooms in Poland. The tests of reverberation conditions were supplemented by the measurements of acoustic insulation of partitions separating the school classrooms from each other and from the corridor. The studies allow to infer that the noise possibly comes from the corridors or adjacent rooms.

1. Introduction

Acoustic protection of buildings affects both the comfort of their users and provides conditions for effective work [1], [2], [3]. The quality of acoustic protection is dependent on the applied acoustic screens [4], [5] and on the acoustic insulation of building partitions [6]. Acoustics is particularly vital for rooms having specific functions such as sacral rooms [7] or school classrooms [8]. The parameters of classroom acoustic assessment include reverberation time [9], optimal reverberation time and assessment indicators [10]. The reverberation time can be calculated with the use of many theoretical models [9], with modified residual minimization method [11], or with the use of perturbation methods [12]. Apart from reverberation time, the so-called Speech Transmission Index [13], [14] can be applied to assess the conditions of verbal sound reception in classrooms. However, according to Bistafa and Bradley [15], reverberation time is the most important parameter describing the acoustics of classrooms. Therefore, the present article examines the reverberation time of the room and the acoustic insulation of building partitions placed in a school building. As a research object we selected a school building, opened in 1877 at the time when Poland was under foreign partitions. The building is located in Zakopane, Poland. The research attractiveness of the building lies not only in its age and wooden construction technology, but also in the fact that it was modernized after the Second World War. Owing to the application of wood paneling and fiberboards, the modernization changed the original acoustic conditions in the building.



2. Methodology

2.1. Description of the building

The Wood Carving School was established by the Tatra Society in Zakopane on July 10, 1876, and it was the first vocational school in Podhale. In the school year 1882/83 the school was moved to a newly built wooden building, which can be still found by Krupówki Street in Zakopane today. The building was designed by an architect from Cracow, Antoni Łuszczkiewicz. In the 1930s an annex was added, and the body of the building has hardly changed to this day. Over the years, the school has evolved and has been used for different purposes. Currently, it houses the Władysław Matlakowski Memorial vocational building construction school complex. The view of the school from the street is shown in Figure 1.



Figure 1. The photos show the view of the school from the street.

2.2. Measurement of reverberation time

The measurements were carried out in the classrooms 2, 3, 4. The volume of the classroom 2 is 183 m³, classroom 3 - 180 m³ and classroom 4 - 168 m³. Inside the classrooms, the floor is covered with linoleum and the walls are covered with paneling up to 1.5 m high.

The reverberation time measurements were made using the intermittent noise method. The measuring system consisted of the transmitting part and the receiving part.

The transmission part of the system comprised the following elements:

- white and pink noise generator with an amplifier,
- loudspeaker with a spherical radiation characteristic.

The reception track comprised the following elements:

- acoustic analyzer,
- microphones,
- preamplifier,
- acoustic calibrator,
- computer with installed software.

The tests were performed for two different positions of the sound source. Six microphone settings were used for each sound source position, and the measurements were repeated six times. The interior was excited with broadband noise shaped in the way to provide an approximately pink steady state reverberation spectrum for the range comprising 1/3 octave bands with center frequencies of 50 - 5000 Hz. The sound source produced a sound pressure level sufficient for the decay curve to start at least 35 dB above the background noise in the relevant frequency range. Figure 2 presents the view of the rooms during the measurement.



Figure 2. View of classrooms 2, 3, 4 during the measurement with an exemplary setting of the speaker ball and measurement points.

2.3. Measurement of acoustic insulation

The measurements were carried out with the use of the measuring system described in section 2.2, whereof components meet the metrological requirements for the accuracy class 1. The tests of acoustic insulation involved the internal partition separating classrooms 2 and 3. To define acoustic parameters of the partition, reverberation time in the examined receiving room (classroom 2) was determined. The measurements were performed using the intermittent noise method. The tests were performed for six microphone positions and two positions of the sound source. To reduce the measurement uncertainty caused by statistical deviations, the measurements were always repeated two times. The reverberation times were determined for each of the 24 sound decay curves. The final result of the test was in the form of arithmetic mean. The view of the classrooms selected for airborne sound insulation tests is presented in Figure 3.

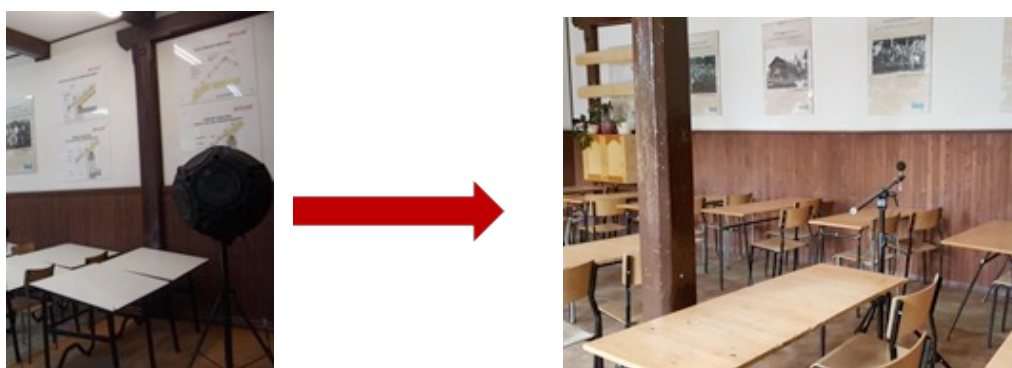


Figure 3. View of the rooms selected for airborne sound insulation tests.

3. Indicators and parameters of acoustic assessment

Let us define the basic concepts for the acoustic assessment of interiors.

Definition 1

Reverberation time (T) – it is a measure of time required for the acoustic pressure to drop by 60 dB after the source of sound is switched off.

Definition 2

Speech Transmission Index (STI) - is a measure ranging from 0 and 1, representing the quality of speech transmission in terms of intelligibility by the speech transmission channel.

Definition 3

Approximate acoustic insulation from airborne sounds - the ability of a building partition to reduce the penetration of airborne sounds through it.

Assessment in terms of STI index

In the study, the STI index was determined using the logarithmic approximation described by the equation [13]:

$$STI = A \ln T + B \quad (1)$$

where: $A = -0.2078$, $B = 0.6488$.

In the model (1), the reverberation time is the average of the following frequencies: 500, 1000 and 2000 Hz.

Assessment in terms of Optimal Reverberation Time

We can assess the acoustics of classrooms on the basis of the optimal reverberation time T_{opt} calculated using the formula:

$$T_{opt} = 0.32 \log V - 0.17 \quad (2)$$

where: V is the volume of the room within the range from 30 to 1000 m³.

T_{opt} should meet the following conditions:

$0.65 \cdot T_{opt} < T < 1.2 \cdot T_{opt}$ for 125 and 4000 Hz bands

$0.8 \cdot T_{opt} < T < 1.2 \cdot T_{opt}$ for 250, 500, 1000 and 2000 Hz bands

4. Results and discussions

The obtained results of reverberation time for the examined classrooms are presented in Figure 4.

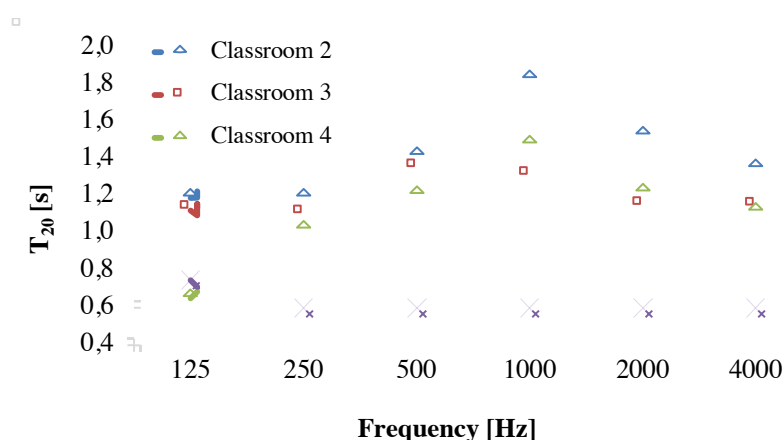


Figure 4. Diagram of reverberation time depending on sound frequency.

Based on Figure 4, we can observe that the school classrooms do not meet the recommended reverberation time duration recommended for classrooms in Europe.

The obtained calculation values of the STI index from the model (1) are presented in Table 1. The STI value in classroom 2 is 0.55 and does not meet Polish requirements being at the level of STI = 0.6.

Table 1. Values of STI indexes.

STI	Obtained values	Recommended value
Classroom 2	0.55	0.6
Classroom 3	0.60	
Classroom 4	0.59	

The determined values of the optimal reverberation times calculated using the formula (2) are presented in Table 2.

Table 2. Values of T_{opt} .

T_{opt}	Obtained values T_{opt}	$0.65 \cdot T_{opt} < T < 1.2 \cdot T_{opt}$	$0.8 \cdot T_{opt} < T < 1.2 \cdot T_{opt}$
Classroom 2	0.55	$0.36 < T < 0.6$	$0.44 < T < 0.6$
Classroom 3	0.55	$0.36 < T < 0.6$	$0.44 < T < 0.6$
Classroom 4	0.54	$0.35 < T < 0.65$	$0.43 < T < 0.65$

It can be observed that the reverberation times T (Fig. 4) do not meet the requirements for optimal reverberation times presented in Table 2. The results of the research on the specific acoustic insulation of the partition are presented in Figure 5.

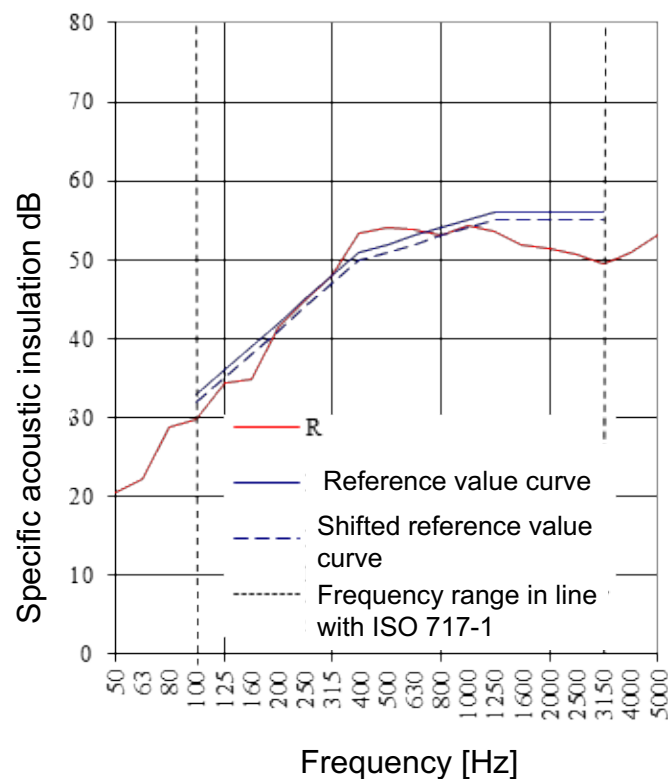


Figure 5. Specific acoustic insulation R determined for the internal partition dividing classrooms 2 and 3.

The determined indexes of approximate acoustic insulation of the tested partition are presented in Table 3.

Table 3. Minimum value of acoustic insulation R'_{A1} for the wall.

Type of internal partition	Insulation against airborne sounds R'_w (C, C_{TR}) [dB]	Obtained value of index R'_{A1} [dB]	Required value of index R'_{A1} [dB]
Wall between classrooms 2 and 3	51 (-1, -5)	50	45

The approximate specific acoustic insulation of the wall between the classrooms, expressed by the index $R'_{A,1}$ was 50 dB.

5. Conclusions

The results of the research on reverberation time presented in this paper clearly demonstrate that the reverberation conditions in the tested classrooms do not meet the minimum requirements for the optimal reception of verbal sound. It can be assumed that the modernization works of the interior initiated in 1945 and taking place for several decades have had negative impact on the acoustics of the interior. It should be noted that the subjective impression indicated that the reverberation noise in the school corridor was very high (due to limited technical capabilities, such studies were not performed). Hence, the high level of noise reaching the classrooms. However, it should be noted that the tests of the acoustic insulation of partitions separating the classrooms and separating the corridor from the classrooms demonstrated very good properties of specific acoustic insulation. This may be related to the fact that modernization did not comprise the building structure, but only finishing of the interior. Thus, the insulation performance remained at the level similar to that when the building was put into use and met the design assumptions.

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