
Improving Speech Intelligibility in A High School Classroom Using Sound Absorbing Panels

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Abstract: - Acoustic comfort has a huge impact on teachers' health and students' productivity. A good acoustic environment can change the child's perception of the teacher. To obtain a good acoustic environment for a school classroom, the background noise and the reverberation time should be as low as possible. Thus, the aim of this investigation is to determine the reverberation time before and after applying sound absorbing materials in a classroom situated in a college from Bucharest. Further on, the measurements were compared with the results obtained from the reverberation time formulas. The speech transmission index was determined based on the reverberation time to highlight how the occupants perceive the classroom from the acoustical point of view. Important issues were discovered in obtaining the optimal reverberation time in schools.

Keywords: - Reverberation time, speech transmission index, classroom, sound absorbing materials

1. INTRODUCTION

Acoustic comfort is another important parameter which can influence the environmental quality of a chamber or a building. The absence of a good environmental quality can highly influence the occupants' perception of the room and, the learning capacity and productivity of the students [1]. It was discovered by being in a classroom with long reverberation time children perceive the teacher as being unfriendly, impatient and with less time to help compared with the children that were taught in classrooms with short reverberation time [2]. Nevertheless, a bad acoustic of a room affects the teacher also, due to intensive use of the voice on a working day leads to a high number of teachers which present voice problems [3]. Thus, acoustic considerations should be considered when designing architectural spaces, especially spaces with destination such as classrooms, conference rooms, theaters or concerts room. Nevertheless, it is not unusual to find classrooms that do not present the basic acoustic standards due to the lack of consideration to the acoustic principles [4]. A study conducted in India showed that the acoustic quality of a vernacular classroom is awfully lower than modern classrooms due to the low insulation performance of the windows [5].

The acoustic comfort can generally be described by two parameters: background noise and

reverberation time. If the reverberation time in classroom is long, teachers tend to raise their voices as an effect of the increased noise levels due to poor attenuation. Even though the reverberation time represents the only parameter that generally determines the acoustics of a room, it is not a predictor of the noise levels during class activity or the speech intelligibility [6]. Speech transmission index defines speech intelligibility by determining the influence of the room on the receiver, meaning exactly what the listener perceived from the sound signal [7]. Applying acoustic treatment on the ceiling of a classroom showed that the speech transmission index has improved by 35%, while the reverberation time decreased with 50 % [8]. On the other hand, the correlation between speech transmission indexes and the exponential of reverberation time decreases as the background noise level increases [9].

There are different ways of determining the reverberation time and they can be applied depending on the destination of the chamber. According to Daheng, Sabine's formula is better to be used for determining the reverberation time on an empty classroom, while Mil-Se's formulas are adapted to determine the reverberation time for a classroom with 2/3 occupancy. Nevertheless, the Mil-Se formulas are good to be used in calculating the influence of the other acoustic materials installed in a room [10].

The absorption coefficients of the surrounding surfaces of an enclosed space represent a very

important parameter in determining the reverberation time. Hence, in 2006, Hodgson presented standard method for classifying the surfaces of a classroom and for determining their areas [11]. Another parameter that could influence the absorptive effect of a classroom consists of the distribution of the occupied seats and different arrangements of the seats [12]. Further on, acoustic conditions can be predicted from measurements with the unoccupied classroom to determine the acoustic performances with different percentage of people occupying the classroom [13].

A study conducted by attaching two types of absorption materials on the ceiling of two identical rooms showed that the difference between the material that presents “Absorption Class A” consisting of a 20 mm panel with glass wool and “Absorption Class E” consisting of a 14 mm panel with wet press mineral wool does not present a significant different effect on the reverberation time. The difference appeared in measuring the speech clarity which increased with 7 dB [14].

The size of a room is not generally an important parameter that influences the verbal communication quality if it was properly designed. According to Hodgson, wide classrooms can present the advantage of keeping the students closer to their teacher, but the big disadvantage of keeping more students to his sides, with the result of not being able to hear due to the fact that the human voice is radiating more sound straight-ahead than to the sides. Thus, a floor-plan shape that presents lengths and widths that are similar, it is the best acoustical solution for a classroom [15].

In this paper, the impact of the sound absorbing materials on the reverberation time was determined in a typical classroom by measuring the reverberation time before and after applying a special material to increase the sound performances of the chamber.

2. EXPERIMENTAL CAMPAIGN

2.1. Classroom description

The experiments took part in a classroom located in college “Mihai Viteazul” which is one of the oldest high schools from Bucharest, Romania. The investigated room can be found at the first floor of the building and it presents the following dimensions: 9 m length, 6.8 m width and 4,9 m height, resulting a total volume of 300 m³. The natural light enters through three identical double wood pane windows of 1.5 m length and height of 2.6 m. The wood door is located at the back of the classroom and it presents 1.3 m length and total height of 2.7 m. A black board is located at the front part of the classroom with a 4 m length and 1.2 m height, resulting a total area of 4.53

m². The floor has a total area of 61.2 m² and it is made of wood, while the walls and ceiling are made of bricks, respectively concrete slab with a plaster layer. The classroom usually shelters 29 students and one teacher. Thus, at the interior it can be found 34 wood desks for students and one for the teacher and 35 chairs.

Figure 1 (a) presents the original classroom, while figure 1 (b) represents the same classroom after applying the sound absorbing panels.



(a)



(b)

Figure 1. The classroom before (a) and after applying the sound absorbing materials (b)

2.2 Experimental results

The experimental campaign was conducted by means of the sound meter Svantek SVAN 979 which presents the possibility of measuring the reverberation time for 1/3 octave band and a frequency range between 3.15 Hz to 20 kHz. The equipment was placed in 9 different points of the classroom as indicated in figure 2. The average value obtained from the points one, two and three was transformed as indicated in figure 3 in a single value representing the front part of the classroom. In the same way were obtained the average values for the middle and back part of the classroom. The equipment was set to measure the reverberation time using the impulse method.

The experimental measurements were first conducted for the unoccupied room without any changes made in the geometrical characteristics of the chamber, while the second part of the experiments was conducted on the same room and for the same points, but only after the application of the sound absorbing materials. For this experiment 34 m² of sound absorbing material was placed on the interior walls except for the front wall, referring to the one sheltering the chalkboard.

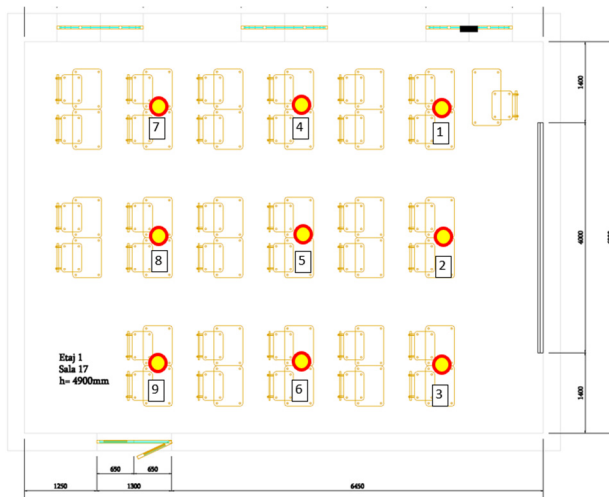


Figure 2. Measurement points inside the analyzed classroom



Figure 3. The average measurement values for the front, middle and back part of the classroom

The two parameters that are the most important in the determination of the reverberation time are the room's destination and the volume. The optimal reverberation time depends specifically on the destination of the chamber, such as, if referring to a concert room, the reverberation time should be higher, while in a conference room it is recommended to be as low as possible in order to have a good intelligibility of the speeches.

Furthermore, the reverberation time is better to be as close as possible for the entire frequency spectrum [13].

The optimal reverberation time for a specific chamber can be determined by using a diagram found in the Romanian Standard for acoustics [16]. After measuring the reverberation time for the two possibilities, with and without sound absorbing materials we found some differences that are presented in the graphic below.



Figure 4. Diagram for determining the reverberation time (RT) in accordance with the Romanian Standard [16]

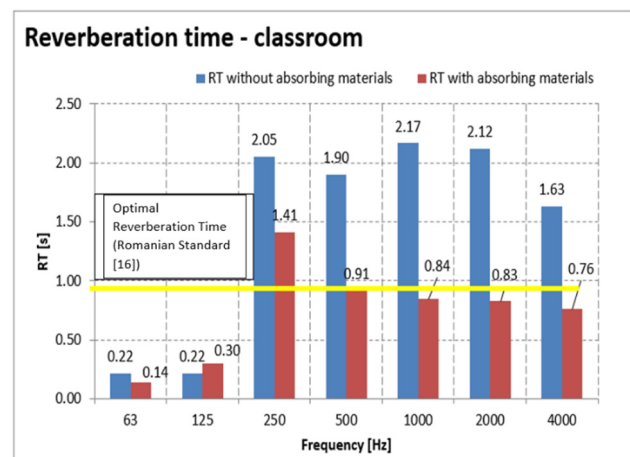


Figure 5. Comparison between the RT60 with and without absorbing materials

The results show that the biggest improvements made to lower the reverberation time (RT) due to the using of the sound absorbing materials, were achieved for higher frequencies from 500 Hz to 4000 Hz, while the smallest one was obtained for the frequency of 63 to 125 Hz.

Further on, the yellow line represents the optimal reverberation time in accordance with the [16]. It shows that the optimal value of the reverberation time for a classroom of 300 m³, like the one in this case, it should be 0.95 s. The graphic highlights the fact that before applying sound absorbing materials, the reverberation time was way too high for this chamber.

After applying the sound absorbing material, the reverberation time has lower values which meet the Romanian standard. The indoor acoustic comfort was greatly improved by this action.

3. NUMERICAL CALCULATIONS

For this part of the study case three formulas for determining the reverberation time were used and they are discussed as follows:

3.1 Determining the reverberation time using Sabine's formula

$$RT = \frac{0.161V}{\sum S\alpha} \quad (1)$$

where V represents the volume of the room, S is the interior surfaces, while α represents the absorption coefficient of the material.

3.2 Determining the reverberation time using Eyring's formula

$$RT = \frac{0.161V}{S_t(-\ln(1-\alpha_0))} \quad (2)$$

where V is the volume of the analyzed chamber, S_t represents the interior surfaces of the room, such as walls, ceiling and floor and α_0 represents the average absorption coefficient of the interior materials.

$$\alpha_0 = \frac{\sum S_i\alpha_i}{\sum S_i} \quad (3)$$

3.3 Determining the reverberation time using Mil-Se formula

$$RT = \frac{0.161V}{\sum -S_i \ln(1-\alpha_i)} \quad (4)$$

where V represents the volume of the occupied chamber, S_i is the interior surface and α_i the absorption coefficient of the material, while $-\ln(1-\alpha_i)$ is the effective sound absorption coefficient.

Table 1 presents all the interior surfaces found in the analyzed chamber that may influence the reverberation time achieved. Further on, the sound absorbent coefficients of every construction material found inside the classroom was mentioned for the frequencies between 125 – 4000 Hz indicated in the Romanian Standard [16].

The results showed that the reverberation time obtained by using Eyring's formula presents the highest level of errors for the frequencies between 125 Hz and 4000 Hz. On the other hand, Sabine and Mil-Se formulas presented better results than Eyring and, closer to one another. It can be seen in the graphic below that the formulas approximate better the reverberation time for the frequency of 1000 Hz, while the lower frequencies are difficult to be predicted. Further on, it can be mentioned that for the 1000 Hz frequency, Sabine's formula presented the closest results to the actual reverberation time

measured with a relative error of 6.4 %, while the Mil-Se formula of 2.4%.

Table 1. The sound coefficient absorbent used for calculations

f [Hz]	125	250	500	1000	2000	4000
S walls [m ²]	137.7	137.7	137.7	137.7	137.7	137.7
α plaster layer [-]	0.04	0.05	0.06	0.08	0.04	0.06
S floor [m ²]	61.2	61.2	61.2	61.2	61.2	61.2
α wood floor [-]	0.04	0.04	0.07	0.06	0.06	0.07
S ceiling [m ²]	61.2	61.2	61.2	61.2	61.2	61.2
α ceiling [-]	0.04	0.05	0.06	0.08	0.04	0.06
S window [m ²]	13.6	13.6	13.6	13.6	13.6	13.6
α window [-]	0.15	0.05	0.03	0.03	0.02	0.02
S door [m ²]	3.51	3.51	3.51	3.51	3.51	3.51
α door [-]	0.15	0.11	0.09	0.07	0.06	0.06
S chalkboard [m ²]	4.8	4.8	4.8	4.8	4.8	4.8
α chalkboard [-]	0.01	0.01	0.01	0.01	0.02	0.02
S table [m ²]	12.4	12.4	12.4	12.4	12.4	12.4
α table [-]	0.01	0.03	0.01	0.03	0.04	0.08
S chair [m ²]	6.13	6.13	6.13	6.13	6.13	6.13
α chair [-]	0.02	0.02	0.03	0.04	0.04	0.04
α absorbing panels [-]	0.06	0.27	0.68	0.93	0.98	0.92
S absorbing panels [m ²]	34	34	34	34	34	34

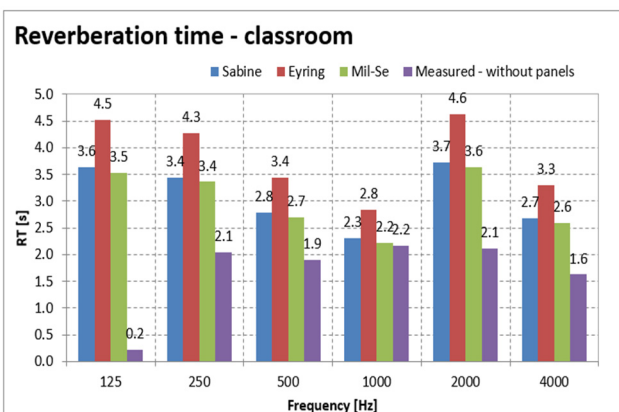


Figure 6. Reverberation time determined with numerical methods – before applying the sound absorbing panels

Furthermore, the same calculus was applied for the investigated room presenting the sound absorbing panels. Interesting results came out for this new determination where the Eyring's formula showed results very close to actual RT measured

experimentally. On the other hand, Sabine's formula and Mil-Se formula showed results that presented an absolute error of 0.26 s, respectively 0.52 s.

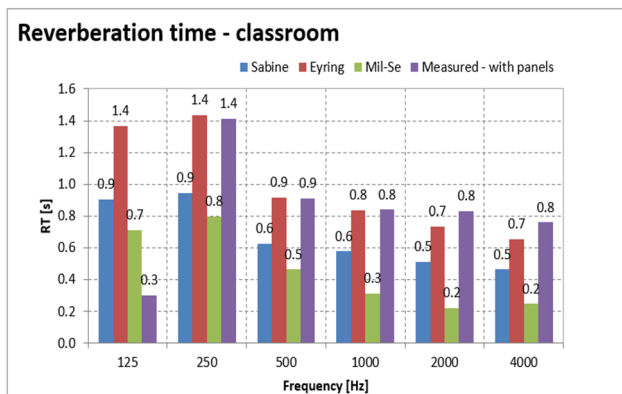


Figure 7. Reverberation time determined with numerical methods – after applying the sound absorbing panels

The speech transmission index (STI) represents also an important parameter and it can be determined from the following formula:

$$m(f) = \frac{1}{\sqrt{1+(2\pi f \frac{RT}{13.8})^2}} * \frac{1}{1+10^{(-SNR)/10}}, \quad (5)$$

where m represents the modulation transfer function, f is the frequency, RT is the reverberation time and the effective signal-to-noise ratio SNR.

Based on the reverberation time measured before, the speech transmission index was calculated for three different points inside the classroom as shown in figure 3.

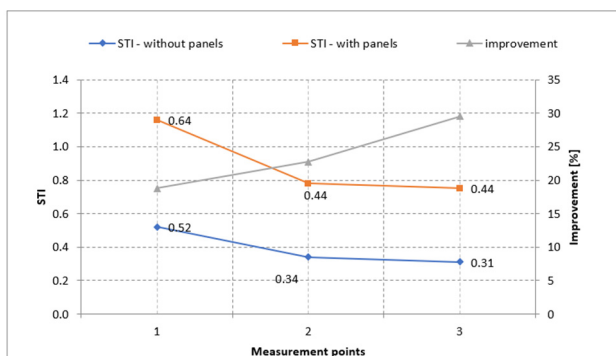


Figure 8. Speech transmission index for the measurement points

According to the European Norm 60268-16:2011, the speech transmission index for a classroom should present values higher or at least the same as 0.62, meaning a good speech intelligibility for complex messages with familiar words.

The graphic from figure 8 shows that the speech transmission index decreases with increasing distance from the teacher's position. For the students positioned in the front benches, they can benefit

of higher values than the students positioned in the back part of the classroom. Furthermore, before installing the sound absorbing materials on the three walls, none of the measuring points fulfills the minimum STI value of 0.62 for a classroom, while after installing the sound-absorbing materials the STI started to achieve better values that can reach 0.64. The absorbing materials brought an important improvement to the speech transmission index up to 30 %. It is important to be mentioned that the speech transmission index was determined for 250 – 4000 Hz.

4. CONCLUSIONS

The study presents the importance of a good acoustic classroom and the impact on the teacher health and the children's perception of the learning time. The experimental part showed the improvement of the reverberation time before and after applying sound absorbing materials on the walls. Comparing with the Romanian norm it could be discovered that the reverberation time for a normal classroom presents values way too high which can determine voice problems for teachers and students. Further on, using the three different formulas for determining the reverberation time of the classroom based on the interior materials and comparing the results with the measured ones, it could be highlighted the differences between them. Regarding the numerical approach, the results for the three formulas used presented various changes throughout different stages of the experiments. Therefore, we could not clearly recommend which of the three could be used for more accurate results.

Another important parameter in establishing the acoustic perception of a room was also determined. The speech transmission index was determined for three different points in the classroom based on the reverberation time measured and it showed that after applying the sound absorbing materials, the STI presented values that met the European legislation meaning that the speech intelligibility grew along with the sound signal perceived by the receiver.

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REFERENCES

- [1] Ricciardi P, Buratti C, Environmental quality of university classrooms: Subjective and objective evaluation of the thermal, acoustic and lighting comfort conditions, *Building and Environment*, Vol.127, 2018, 23–36
- [2] Kristiansen J, Lund S, Nielsen P, Persson R, Shibuya H, Determinants of noise annoyance in teachers from schools with different classroom reverberation times, *Journal of Environmental Psychology*, Vol.31, 2011, 383 – 392
- [3] Durup N, Shield B, Dance S, Sullivan R, Gomez-Agustina L, How classroom acoustics affect the vocal load of teachers, *Energy Procedia*, Vol.78, 2015, 3084 – 3089
- [4] V Gómez Escobar, JM Barrigón Morillas, Analysis of intelligibility and reverberation time recommendations in educational rooms, *Applied Acoustics*, Vol.96, 2015, 1–10
- [5] John J, Thampuran A L, Premlet B, Objective and subjective evaluation of acoustic comfort in classrooms: A comparative investigation of vernacular and modern school classroom in Kerala, *Applied Acoustics*, Vol.104, 2016, 33–41
- [6] Rantala L, Sala E, Associations between classroom conditions and teacher's voice production, *Energy Procedia*, Vol.78, 2015, 3120 – 3125
- [7] Daheng Y, Qi L, Research of Computer Simulation of Reverberation Time in Classroom, *Physics Procedia*, Vol.33, 2012, 1677 – 1682
- [8] Hodgson M, Scherebnyj K, Estimation of the absorption coefficients of the surfaces of classrooms, *Applied Acoustics*, Vol.67, 2006, 936–944
- [9] Young-Ji Choi, Effect of occupancy on acoustical conditions in university classrooms, *Applied Acoustics*, Vol.114, 2016, 36–43
- [10] Young-Ji Choi, Predicting classroom acoustical parameters for occupied conditions from unoccupied data, *Applied Acoustics*, Vol.127, 2017, 89–94
- [11] Campbell C, Nilsson E, Svensson C, The same reverberation time in two identical rooms does not necessarily mean the same levels of speech clarity and sound levels when we look at impact of different ceiling and wall absorbers, *Energy Procedia*, Vol.78, 2015, 1635 – 1640
- [12] Hodgson M, Case-study evaluations of the acoustical designs of renovated university classrooms, *Applied Acoustics*, Vol.65, 2004, 69–89
- [13] Nowos'wiat A., Olechowska M, Fast estimation of speech transmission index using the reverberation time, *Applied Acoustics*, Vol.102, 2016, 55–61
- [14] Peng J, Wang D, Lau S, Yan N, Jiang P, Wu S, an investigation of acoustic treatment for children in a classroom of an elementary school, *Applied Acoustics*, 89, 2015, 42–45
- [15] Tang S, Yeung M, Reverberation times and speech transmission indices in classrooms, *Journal of Sound and Vibration*, Vol.294, 2006, 596–60
- [16] C 125/1 – 2012, Normativ privind Acustica in constructii si zone urbane
- [17] EN 60268-16:2011 - Sound system equipment - Part 16: Objective rating of speech intelligibility by speech transmission index.