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Research paper

Teachers' and Students' Assessment of the Influence of School Rooms Acoustic Treatment on Their Performance and Wellbeing

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The paper presents the latest research results concerning the correlation between changes in the room acoustics of school spaces and noticeable changes in the communication and functioning of students and teachers at school.

The primary school covered by the research is the second largest school of this type in Poland. The large number of students and hard interior finishing made the acoustic conditions in the school building very unfavourable. The measurements showed that school rooms were very noisy and reverberant. The measured values of reverberation time T were in many rooms 3–4 times higher than the acceptable values specified in the mandatory Polish acoustic standard PN-B-02151-4:2015-06. Also the speech intelligibility measured by the speech transmission index was very poor, in the extreme case STI = 0.31. This situation (very characteristic for most of Polish schools) became the basis for the first such comprehensive acoustic treatment of the whole school building in Poland. This intervention allowed to meet PN-B-02151-4:2015-06 demands almost in every room accessible for students. This case gave an excellent opportunity to assess the influence of improved room acoustics on teachers' and students' performance and wellbeing.

Measurements of the equivalent sound level L_{Aeq}, reverberation time T and STI speech transmission index were made before and after acoustic treatment. The questionnaire survey used the Acoustic Change Feelings Scale (ACFS-S, ACFS-T) for teachers and students. 378 students, and 44 teachers were included in the study. Both students' and teachers' answers show significant improvement of their performance and wellbeing. Positive changes were noticed in students' level of concentration, short memory capacity and pace of work. After acoustic treatment students (both in teachers' and their own opinion) can better hear and understand teachers' instructions and are much more capable of task fulfilling. Both teachers and students observed clear reduction of aggression level. Teachers reported considerable drop in students' fatigue and their own voice effort.

Keywords: acoustic treatment of school rooms; changes in the functioning of students and teachers; acoustic change feelings scale.

1. Introduction

There are over 22 thousand primary and secondary schools in Poland. The vast majority of rooms in the buildings in which these institutions operate is devoid of any solutions providing good room acoustics. In the case of these few buildings, where the room acoustic was thought about when designing and constructing, only selected rooms were usually covered by the acoustic project. Very few buildings in Poland have a comprehensive solution to the problem. The reason for this is a relatively low awareness of the importance of the acoustics of school rooms for the well-being, efficiency and sometimes even the health of their users. This awareness is low both among the designers of school buildings and the officials responsible for the development and maintenance of the school base. This is due to deficiencies in the syllabus at the faculties of architecture and perhaps, first of all, due to the lack of suitable regulations. This unfavourable situation began to change due to the PN-B-02151-4: 2015-06 standard published in 2015 (Polish Norm, 2015), which is the first Polish Standard that defines requirements in relation to the room acoustics in public buildings (it lists as many as 19 types of rooms that appear in the school facilities). The significance of this standard increased after 1 January 2018, when it became mandatory (it is invoked in the Regulation of the Minister of Infrastructure of 12 April 2002 on the technical conditions which should be met by buildings and their location, amended on 1 January 2018). In the Regulation of the Minister of National Education and Sport of 31 December 2002 (as amended) on health and safety in public and non-public schools and facilities, there is still no word about the acoustic conditions in schools.

Meanwhile, Koszerny and Jankowska (1995) drew attention to the noise in Polish schools in the 1990s. Measurements carried out in the Warsaw primary schools by Augustyńska *et al.* (2010) also pointed to high sound levels in the school corridors, canteens, sport halls as well as in after-school clubs and classrooms. As part of the same research, a survey was conducted among the teachers, in which they explicitly pointed to noise as the most common physical nuisance which they are exposed to at their workplace. Measurements made by Mikulski and Radosz (2011) showed, however, excessive reverberation of the classes in these schools as well as low STI values. Kotus *et al.* (2010) analysed the impact of the acoustic treatment on the noise level in the school corridors of two Warsaw elementary schools. Wróblewska and Leo (2012) analysed the impact of classroom acoustic treatment on speech intelligibility measured by objective and subjective methods. The results indicated very poor speech intelligibility in a typically finished room.

Foreign studies include a lot of papers presenting the results of measurements of the sound level measured in classrooms during classes as well as the results of measurements of reverberation time and STI in these rooms: (Shield, Dockrell, 2004; Wallinder *et al.*, 2007; Sato, Bradley, 2008; Astolfi, Pellerey, 2008; Ana *et al.*, 2009; Zannin, Zwirtes, 2007; Waye *et al.*, 2010; Golmohammadi *et al.*, 2010; Bottalico, Astolfi, 2012; Ali, 2013; Sarantopolous *et al.*, 2014; Lyberg Ahlander *et al.*, 2014; Durup *et al.*, 2015; Whiting *et al.*, 2015; Shield *et al.*, 2015; Choi, 2016; 2018; Silva *et al.*, 2016; Sala, Rantala, 2016; Cutiva *et al.*, 2017; Dongre *et al.*, 2017; Peng *et al.*, 2018; Shield, Carey, 2007; Zannin, Loro, 2007; Klatte *et al.*, 2010; Escobar, Morillas, 2015; John *et al.*, 2016; Moodley, 1989; Hay, 1995; Mackenzie, 2000; Lundquist *et al.*, 2000). The measured values of reverberation time differ significantly, which is no surprise taking into account the differences between the studied classrooms (volume, finishing, furniture and equipment). Nevertheless, a general conclusion can be drawn that without the use of additional sound-absorbing solutions on ceilings and walls, it is difficult to achieve reverberation conditions that meet the national standard requirements. The sound levels measured during classes in the classrooms were also very diverse which, of course, corresponds to various forms of classes. It is important that virtually every study showed in certain situations $L_{\mathrm{Aeq}} > 70$ dB levels and some of them much higher levels ($L_{\mathrm{Aeq}} > 80$ dB). This means that in certain forms of classes, the classrooms can be as loud as the canteens or the corridors.

There are slightly fewer papers which give the results of similar measurements conducted in school rooms other than classrooms: (Shield, Dockrell, 2004; Golmohammadi *et al.*, 2010; Pellegrin-Garcia *et al.*, 2012; Bulunuz *et al.*, 2014; Sarantopolous *et al.*, 2014; Escobar, Morillas, 2015; Shield *et al.*, 2015; Pinho *et al.*, 2018). They imply that the same types of rooms are the noisiest ones: corridors, canteens and sport halls. This, of course, applies to the situation when students are staying in these rooms.

There are also many papers that relate to the impact of noise in the classroom and its acoustics on the cognitive abilities of students. Even if studies that relate only to the impact of traffic noise are omitted, there are still many such papers: (Elliott, 2002; Beaman, 2005; Elliott, Briganti, 2012; Meinhardt-Injac *et al.*, 2015; Joseph *et al.*, 2018; Klatte *et al.*, 2007; 2010a, 2010b; Dockrell, Shield, 2006; Shield, Dockrell, 2004; 2008; Ronsse, Wang, 2010; 2013; Lunquist *et al.*, 2000; Ljung *et al.*, 2009; Shield *et al.*, 2015; 2018; Connolly *et al.*, 2016). These studies show that both the environmental (external) noise and the noise generated in school rooms have a negative impact on the learning progress. Quite often, the attention is paid to the effect of the delay in learning to read and the weakening of reading comprehension, at the later stage of education caused by the noise. Some authors point to a deteriorated ability to memorise information and receive speech, as well as to a weakened motivation and concentration of attention under the influence of noise. Attempts have been made to refer the acoustic conditions in which the students work to the assessments of their standard test scores, finding a negative correlation between the noise level in the classroom and the level of grades. Shorter reverberation time, in turn, allows for better speech intelligibility, especially if it is disturbed by conversations around the listener. It also pointed to more efficient phonological processing in the case of students working in classrooms with shorter reverberation times. The general conclusion of these studies is that in order to provide the students and the teachers with optimal acoustic conditions, it is necessary to reduce the noise reaching the classrooms from the outside (by appropriate location of the school and appropriate construction of external partitions) but also to reduce indoor noise and improve speech intelligibility (by proper acoustic finishing of the very rooms).

However, there are relatively few surveys concerning the subjective assessment of the acoustic environment in schools by the students and the teachers. They refer almost exclusively to classrooms: (Mealings *et al.*, 2015; Astolfi, Pellerey, 2008; Ali, 2013; Connolly *et al.*, 2013; Boman, Enmarker, 2004; Roy, Li, 2013; Klatte *et al.*, 2010b; Dockrell *et al.*, 2013; Enmarker, Boman, 2004; Kristiansen *et al.*, 2011, 2013; Canning, James, 2012). Research shows that the students attach more importance to the acoustic and visual aspects of the surrounding space than air quality and thermal comfort. As one of the most important effects of poor acoustics in the classrooms, they point to a decrease in concentration. Younger students more often report problems with understanding the teacher's speech, they are also more irritated by noise. As the most annoying sounds, both the students and the teachers point to loud conversations in the classroom or in the corridor next to it. The noise is perceived as particularly irritating during tests and reading. Students learning in the classrooms with a relatively long reverberation time more often complain about the noise in the rooms and assess their own commitment and relations with their peers with class and teachers as worse. Teachers working in such rooms, in turn, are more likely to complain about irritability and lack of energy after the classes. They also show less satisfaction with the job. The surveys clearly show that the quieter and less reverberant the classrooms are, the better they are assessed by the students and the teachers. Teachers, however, seem to be more sensitive to noise, more stressed than others, they more often have problems with hearing, which in the conditions of poor acoustics can be a source of communication problems. A special sensitivity to the quality of the acoustic environment among the students with special educational needs is also indicated (the students which require educational support, using hearing aids or students from immigrant families just acquiring a new language).

The comprehensive acoustic treatment of one of the largest primary schools in Poland gave the possibility to conduct a broader survey – in terms of number of types of rooms and situations assessed as well as the number of the students and teachers who could participate in the study. As the study could be carried out shortly after finishing the work, the teachers and students could relate the current situation to the state before the modernisation.

2. Problems of research, measurement methods

The research problem is included in the question:

Whether and to what extent the acoustic treatment of the school rooms influenced students' and teachers' assessment of changes in different aspects of their performance and wellbeing?

The students' and teachers' opinion surveys used the proprietary measurement scale prepared for the needs of this study: Acoustic Change Feelings Scale for teachers and students – ACFS-T and ACFS-S. The scale examined perceived by students and teachers changes in level of: concentration, pace of work, short term memory capacity, fatigue, following simple and complex instructions, task fulfillment, understanding speech communication and level of aggression among students. The respondents completed the scale after the school's acoustic treatment, but assessed the phenomenon "before" and "after" on a 5-step scale.

The studies were based on statistical calculations using a Wilcoxon rank test based on rank values. All calculations were made at the significance level α = 0.05.

2.1. Research area

Primary School no. 340 in Warsaw with its 1200 students was the second largest primary school in Poland before the reform of the school system (2016–2019). The school building was constructed in 2012 according to a design that did not take into account the room acoustics at all. Hard finishing of the rooms and very large number of students meant that the building was loud enough so that the Parent Board started efforts to carry out acoustic treatment. In 2016, the City Council of Warsaw decided to allocate some funds to this task and the works, performed according to the design of dr inż. arch. Andrzej Kłosak (archAKUSTIK) and mgr inż. arch. Weronika Nowak (wmn ARCHITEKCI) was finished in August 2018. Acoustic treatment covered all classrooms, after-school clubs, corridors, lobbies, canteen, auditorium, gymnasiums and sport hall.

2.2. Study population

378 students and 44 teachers participated in the study. The selection of research groups was deliberate due to the first primary school in Poland in which the acoustic treatment was made to such a large extent. The study involved students from the second grade to the eighth grade of the primary school. The most numerous represented classes was the fourth grade (45% of the study population) and the fifth grade (30% of the study population)[1].

[1] The large number of these classes is related to the education reform in 2014 which imposed school duty for children from the age of 6, so in these classes there are both children who started their first grade at the age of both 6 and 7.

3. Results of research

3.1. Acoustic treatment and its effects

Acoustic treatment in school consisted in installation of sound absorbing solutions described in the Table 1. The main objective was to fulfil the demands of PN-B-02151-4:2015-06 standard, although it was sometimes impossible due to existing building limitations. Below are description of some particular rooms cases: applied solutions and measured effects.

3.2. Classrooms

The building has 36 classrooms with the floor surface area between 31.3 m^2 and 72.3 m^2, where most of these rooms (63%) have the surface area between 59.0 m^2 and 67.0 m^2. The height of all classrooms before the treatment was 3.0 m. Floors finished with seamless PVC lining, masonry and plastered walls, reinforced concrete ceiling slabs, plastered. The acoustic treatment consisted in the installation of the following acoustic solutions:

- **Ceilings**: sound absorbing solution B covering from 43.4% to 50.6% of the ceiling area installed around the perimeter of the rooms. Due to the building regulations specifying the minimum height of classrooms, it was not possible to cover the more surface of the ceilings with a sound absorbing material.
- **Walls**: sound absorbing solution B covering from 12.4% to 14.1% of the total wall area mounted on two walls of each classroom (rear and one of the side walls). Panels covering the entire available surface of these walls higher than 200 cm.

Figures 1, 2, and 3 present values of reverberation time (before and after acoustic treatment) measured in 13 classrooms on the first floor. These are 6 classrooms for early school education, 3 language classrooms, and 4 subject classrooms. Values of the speech transmission index STI in three classrooms (one from each category)

Table 1. Sound absorbing solutions used for acoustic treatment.

Solution	Description	Practical sound absorption coefficient α_p					
		125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
A	15 mm thick glasswool tiles installed in modular suspended ceiling 200 mm below the ceiling slab	0.40	0.85	1.00	0.90	1.00	1.00
B	100 mm thick glasswool tiles installed directly against ceiling slab or wall*	0.80	1.00	1.00	1.00	1.00	0.95
C	40 mm thick glasswool tiles installed directly against ceiling slab or wall	0.25	0.80	1.00	1.00	1.00	0.90
D	40 mm thick glasswool tiles (impact resistant) installed directly against ceiling slab or wall	0.25	0.75	1.00	1.00	1.00	1.00
E	100 mm thick glasswool tiles (impact resistant) installed directly against ceiling slab or wall	0.80	1.00	1.00	1.00	1.00	0.95

* Estimated values.

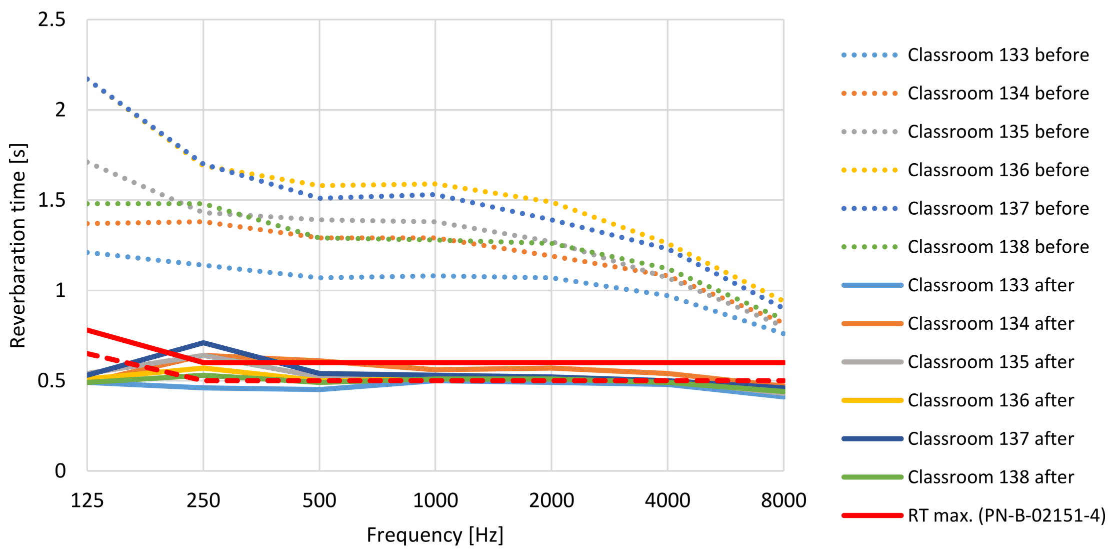

Fig. 1. Classrooms (early education) at 1st floor, reverberation time RT [s] before and after acoustic treatment.

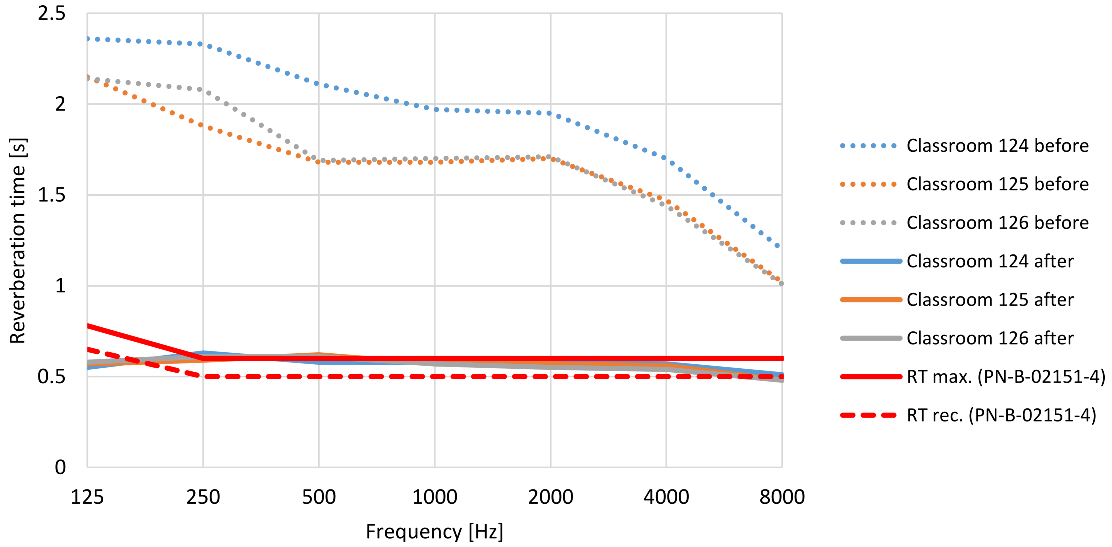

Fig. 2. Classrooms (language education) at 1st floor, reverberation time RT [s] before and after acoustic treatment.

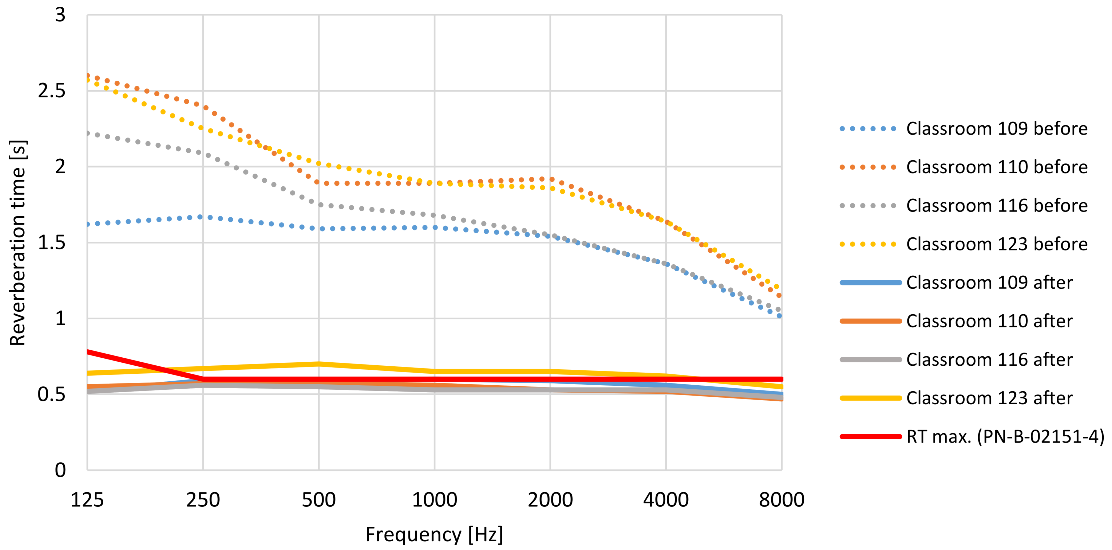

Fig. 3. Classrooms (others) at 1st floor, reverberation time RT [s] before and after acoustic treatment.

were measured. Table 2 presents the results. Due to the similar dimensions and finishing of the classrooms on the second floor, the measured values of the reverberation time and STI speech transmission rate are very similar.

Reverberation time. Despite the limitations mentioned above, the basic requirements of the standard for classrooms have generally been met, subject to minor exceeds of the permissible values in few cases. These exceedances occurred mainly within the 250 Hz octave band and were usually no more than 5%, which is permitted by the standard. These exceedances occurred in the classrooms in which the furnishing was more modest or in which there were additional building restrictions resulting in a smaller amount of sound absorbing materials introduced. At the same time, it

Table 2. Speech transmission index STI values measured before and after acoustic treatment in selected classrooms.

Room	Speech transmission index STI					
	PN-B-02151-4 demands		Before treatment		After treatment	
	(average)	(lowest)	(average)	(lowest)	(average)	(lowest)
Classroom 116 – Polish language	0.60	0.55	0.49	0.46	0.71	0.68
Classroom 124 – English language	0.60	0.55	0.47	0.45	0.70	0.68
Classroom 137 – early education	0.60	0.55	0.52	0.50	0.72	0.69

should be noted that among 9 classrooms for early education and linguistic teaching only one met the tougher recommendations of the same standard regarding these type of classrooms.

STI speech transmission index. As a result of the acoustic treatment, a significant improvement was achieved by increasing the averaged STI values by 0.20–0.23 for each room. Thus, the requirements of the standard were met with a large margin.

Reverberation time values measured in all classrooms before acoustic treatment were very high compared to the requirements of the standard. They were also quite high when compared to the results of measurements performed in standard finished (that is, no sound absorbing materials on ceilings and/or walls) classrooms in other countries. This is due to the fact that the classrooms at Polish schools are relatively spacious and hard-finished. It is possible to see here the influence of both regulations and building tradition. According to the Polish building regulations, the height of a classroom cannot be lower than 300 cm but most schools built in the post-war period have 315–325 cm high classrooms. In combination with the average surface of these rooms, which is approx. 65 m^2, this gives the volume of 200–210 m^3. In addition, the walls in Polish schools (including the partition walls) are almost without exception masonry and plastered.

3.3. After-school clubs

There are 6 after-school clubs in the school with the floor surface area between 63.1 m^2 and 65.2 m^2. The height of all such rooms before the acoustic treatment was 3.3 m. Floors finished with seamless PVC lining, masonry and plastered walls, reinforced concrete ceiling slabs, plastered. The acoustic treatment consisted in the installation of the following acoustic solutions:

- **Ceilings:** sound absorbing solution A covering the entire surface of the rooms.
- **Walls:** sound absorbing solution B covering from 16.0% to 17.0% of the total wall area mounted on two walls of each room (rear and one of the side walls). Panels covering the entire available surface of these walls above the height of 200 cm.

Measurement of reverberation time before and after acoustic treatment was performed in all 6 after-school clubs. The achieved reduction of the reverberation time value is presented in Fig. 4.

The acoustic treatment made it possible to meet the requirements of the standard for after-school clubs in all such rooms in the school.

3.4. Sport hall

The sport hall has the floor surface area of 1068.0 m^2 and volume of 11,072.0 m^3. There are masonry and plastered walls, sports floor on joists, a single-sided roof with a structure made of glued laminated timber and covering with sandwich panels. Due to concerns regarding the load-bearing capacity of the roof structure, the designers decided to introduce sound absorbing solutions only on the walls of the hall.

On both gable walls and on one of the longitudinal walls, 50 cm to 370 cm high (from the floor level), sound absorbing solution D was installed.

On all walls of the sport hall, above the height of 370 cm (from the level of the floor), sound absorbing solution E was mounted.

The total area of sound absorbing solutions is 77.3% of the total wall surface area. The achieved reduction of the reverberation time value is presented in Fig. 5.

The acoustic treatment resulted in meeting the requirements of the standard for sport halls with a vo-

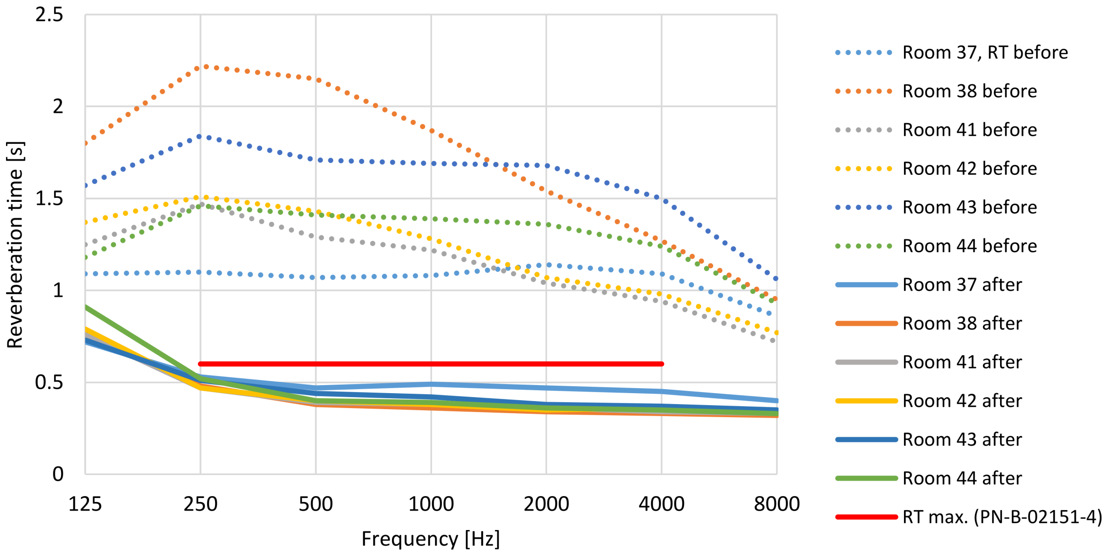

Fig. 4. After-school clubs, reverberation time RT [s] before and after acoustic treatment.

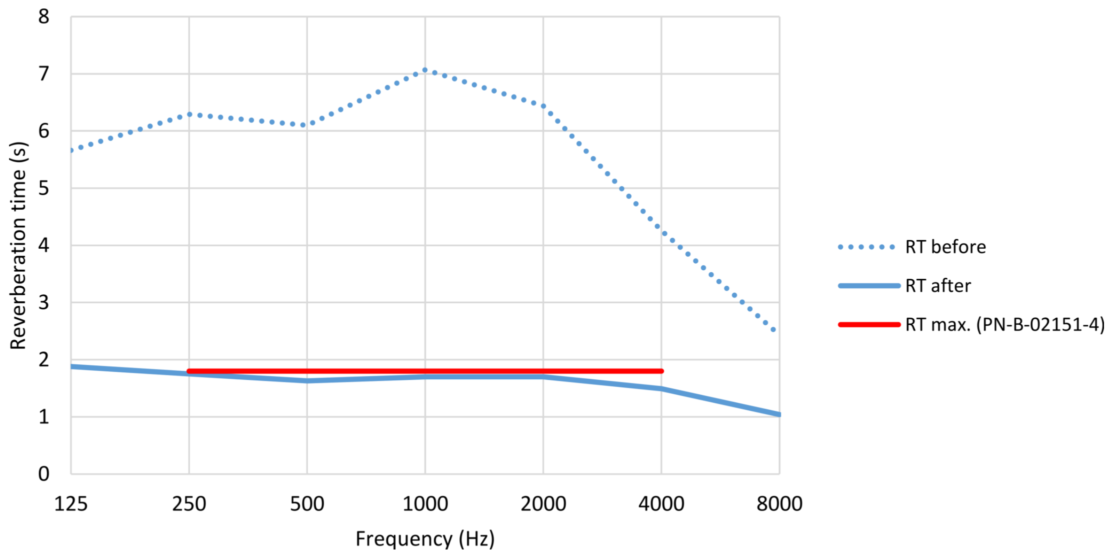

Fig. 5. Sport hall, reverberation time RT [s] before and after acoustic treatment.

lume over 5.000 m^3. It was also possible to meet the additional recommendation of the standard, which says that in rooms with a large cubic capacity, in which a sound system installation is planned, the reverberation time in 125 Hz band should be close to the reverberation time within 500 and 1000 Hz bands.

3.5. Corridors and halls

The layout of each storey of the building are organised around of spacious hall (670 cm wide) converging narrower corridors (313–340 cm wide). The height of the corridors and halls before the acoustic treatment was 330 cm (ground floor) and 300 cm (1st and 2nd floor). Masonry and plastered walls, reinforced concrete ceiling slabs, plastered, floor finished with seamless PVC lining. The acoustic treatment consisted in the installation of the following acoustic solutions:

- **Ceilings:** sound absorbing solution A covering the entire available ceiling area (in many places it is limited by the plasterboard casing of the building technical services).
- **Walls:** sound absorbing solution C installed on available wall sections above the height of 200 cm.

Table 3 presents the calculation values of an equivalent sound absorption area for the 1st floor corridors before and after the acoustic treatment. The requirements of the standard have been met with a large margin. The results for the ground floor and the 2nd floor are slightly weaker due to the lower degree of ceiling coverage with sound absorbing solutions (a larger area of the ceiling covered by plasterboard service casing), but in most cases the requirements were also met here.

A significant increase in sound absorption of most rooms in the school led to a significant reduction in the sound level in these rooms. Before and after the modernisation, a number of random sound level measurements were carried out to capture the scale of the phenomenon. Table 4 presents the results.

Measurements of reverberation time and speech transmission index (both before and after refurbishement) were made as part of the acoustic project by archAKUSTIK studio from Cracow. Reverberation time measurements were made in accordance with Polish Norm (2008), using the technical method. STI values were measured in accordance with Polish Norm (2011), using the "Full STI" method. The background noise level during STI measurements was very low (close to

Table 3. Corridors at 1st floor, equivalent sound absorption area A [m^2].

Room	Floor surface S [m^2]	Equivalent sound absorption area A [m^2]				
		Demanded according to PN-B-02151-4	Calculated			
				500 Hz	1 kHz	2 kHz
Corridor 1B	137	≥ 137	before	18	20	26
			after	193	181	198
Corridor 1C	195	≥ 195	before	25	26	33
			after	225	211	231
Corridor 1A	214	≥ 214	before	21	23	29
			after	255	236	260

Table 4. L_{Aeq} values measured before and after acoustic treatment in selected rooms.

Room	Activity	Remarks	L_{Aeq} [dBA]	
			Before	After
Sport hall	Dodge ball	40 students involved in the play in central sector of the hall; in side sectors two other groups of 20 students each occupied with quieter tasks	82.0	75.7–76.3
After-school club	Free activity	30 students playing in groups	79.2–81.5	72.8–77.2
Hallsecond floor	Break	50–70 students, no smartphones allowed	81.4–86.9	73.8–80.0
Canteen	Lunch	70–140 students	85.5–86.0	73.4–76.6

25 dBA), so STI values were set down for background noise level of 35 dBA (the maximal permissible noise level from the building technical equipment according to PN-B-02151-2).

Initial (before acoustic treatment) measurements of the sound level in school premises were performed by the employees of the Central Institute for Labour Protection – the National Research Institute, and the as-built measurements were performed by Mikołaj Jarosz.

3.6. Results of questionnaire survey among the students and teachers

The changed acoustics of the school presented in the above material was the motive for research to answer the question whether changes in the acoustics are noticed by the students and teachers. If they are, in what ranges these changes are visible.

The students expressed their opinions in the ACFS-S questionnaire sheets (20 questions on a scale from 1 to 5, where 1 is the lowest rating, 5 – the highest rating) and teachers in the ACFS-T (33 questions on a scale from 1 to 5, where 1 is the highest rating, 5 – the lowest rating). Most of the questions in both scales were extended, of a multiple-choice matrix type.

3.7. General questions

A crucial and very difficult question for the students was the issue of assessing changes in various areas after acoustic treatment. When considering the complexity of such assessment and, at the same time, the difficulty in assessing the situation by children after a few months of working in improved acoustic conditions, the students pointed to the situations which have changed according to them. Table 5 presents the results.

The presented data show that the most numerous group of students noticed changes in the classroom, according to them the class is more quiet (43.12%) and they better understand teachers' instructions (26.46%). Another place where the students observe changes are school corridors; in their opinion it is now quieter during breaks (40.74%) and they better understand teachers' instructions (17.99%). Better speech intelligibility in the gymnasium was noticed by 21.16% of students.

Teachers' answers within the observed changes in the functioning of school after the acoustic treatment of the school are presented in Table 6 (changes in work with the students) and in Table 7 (changes in teacher's work condition).

Teachers' responses show that the greatest changes in the students' functioning are observed in terms of the students' understanding of verbal instructions during classes (61.36%) and in communication with students during breaks (61.36%). In the second place, in the student's individual work (43.18%).

The teachers see changes within their own work conditions mainly in improving the overall comfort of work (77.27%), secondly in the level of voice fatigue after a full day of work (45.45%) and change of work comfort during duties in the corridors (43.18%).

Table 5. Changes after acoustic treatment of the school noticed by the students.

Observed changes	Number of answers ($N = 378$)	Percentage [%]
It is more quiet in classrooms	163	43.12
It is more quiet in corridors	154	40.74
Children run less now in corridors	18	4.76
Children quarrel less	19	5.03
I can better understand the teacher in classrooms	100	26.46
I can better understand the teacher in the gymnasium	80	21.16
I can better understand the teacher in the corridor	68	17.99

Table 6. Changes after the school acoustic treatment observed by teachers – students' performance and behaviour.

Observed changes	Number of answers ($N = 44$)	Percentage [%]
In student's individual work	19	43.18
In the students' team work	15	34.09
In the level of understanding verbal instructions in classes	27	61.36
In the students' behaviour during breaks	15	34.09
In communication with the students during breaks	27	61.36
Other	3	6.82

Table 7. Changes after the school acoustic treatment observed by a teacher – teacher's work conditions.

Observed changes	Number of answers ($N = 44$)	Percentage [%]
Improved general comfort of work	34	77.27
Improved health - generally	8	18.18
Changes in fatigue level after working day	18	40.91
Changes in vocal fatigue level after working the day	17	38.64
Changes in vocal effort during the day	20	45.45
Changes of work comfort while on duty in corridor	19	43.18
Changes during events organised in the gymnasium	13	29.55
Changes during events organised in the school corridors	7	15.91
Other	2	4.55

3.8. Detailed questions

Both teachers and students were answering detailed questions related to changes in different aspects of their school activity.

In all statistical calculations, the hypothesis H_0 was assumed that the average results of the assessments determined by the respondents (before and after acoustic treatment) are significantly **equal** and the alternative hypothesis H_1 that the average results of assessments determined by the researched subjects (before and after acoustic treatment) are significantly **different**.

3.9. Students

The students assessed changes in independent work in the classroom before and after the acoustic treatment in terms of focusing attention, hearing and understanding teacher's instructions. The results of research in this area are presented in Tables 8 and 9.

The results in the table above indicate the basis for rejecting H_0 hypothesis and accepting hypothesis H_1 as true, i.e. the average results of the students' assessments (before and after the acoustic treatment) are statistically different in all three areas of the study – level of concertation, hearing and understanding the teacher's instructions.

Table 9 presents the average results of assessments determined by the students for the identification of the direction of change.

The analysis of average results of the assessments determined by the students' points to statistically higher grades obtained after the acoustic treatment in all three areas of the study - level of concertation, hearing and understanding teacher's instructions. Therefore, the acoustic treatment of the school in the opinion

Table 8. Wilcoxon sign rank test results – changes observed by the students – students' individual work.

Students assessment	Level of concentration before and after quieting[a]	Hearing teacher's instructions before and after school quieting	Understanding teacher's instructions before and after school quieting
Z	−9.410	−8.812	−8.064
p-value	0.000	0.000	0.000
Conclusion	as $\alpha > p$-value, hypothesis H_0 is rejected and we **accept H_1** as true	as $\alpha > p$-value, hypothesis H_0 is rejected and we **accept H_1** as true	as $\alpha > p$-value, hypothesis H_0 is rejected and we **accept H_1** as true

[a] In studies among the students, the term "quieting" was used for the children to better understand the concept of the "acoustic treatment of school".

Table 9. Changes observed by the students – students' independent work.

Changes in the independent work in the classroom – student's assessment		Average assessment[b]	N	Standard deviation	Conclusions on the basis of the average assessments
Pair 1	level of concentration **before** quieting	3.06	378	1.126	level of concentration after quieting **is statistically higher** than before it
	level of concentration **after** quieting	3.71	378	1.087	
Pair 2	hearing teacher's instructions **before** school quieting	3.24	378	1.107	hearing teacher's instructions after school quieting **is statistically higher** than before it
	hearing teacher's instructions **after** school quieting	3.89	378	1.038	
Pair 3	understanding teacher's instructions **before** school quieting	3.31	378	1.076	understanding teacher's instructions after school quieting **is statistically higher** than before it
	understanding teacher's instructions **after** school quieting	3.85	378	1.052	

[b] The higher the average assessment given by the students, the better the result – according to the scale adopted in the survey.

of the students positively influenced their functioning in this area.

This method of statistical analysis has been adopted into all research areas both from the point of view of the students and teacher. Figures 6 and 7 shows students answers related to level of concentration and pace of work.

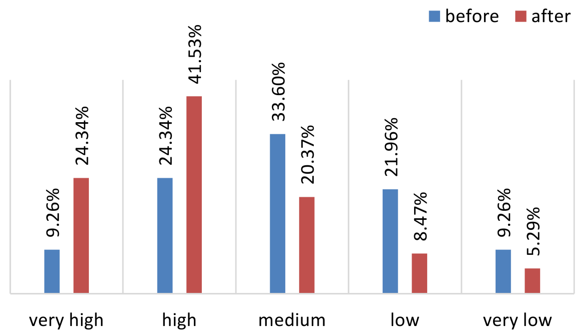

Fig. 6. Students' level of concentration on task during individual work, assessment made by students.

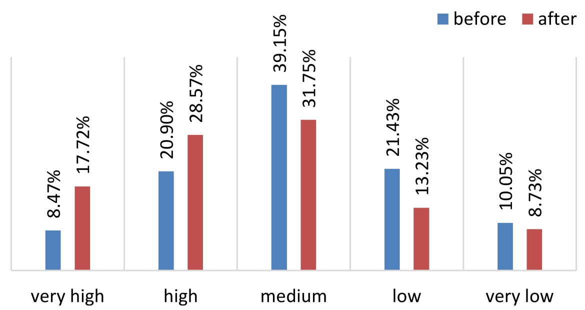

Fig. 7. Students' pace of work during afternoon lessons, assessment made by students.

In their research many authors raise the issue of noise-induced fatigue. This was mentioned in the introduction to this article. Also in our own research we sought confirmation of this phenomenon in the opinions of the teachers. That cannot be said about students' answers. Tables 10 and 11 present students' opinions on the level of their fatigue during school day.

Table 10. Wilcoxon sign rank test results – changes observed by the students – level of students' fatigue.

Level of students' fatigue	Level of fatigue during the morning lessons, before and after school quieting	Level of fatigue immediately before the lunch break, before and after school quieting	Level of fatigue during afternoon lessons, before and after school quieting
Z	-0.666^a	-1.207^a	-0.941^a
p-value	0.506	0.228	0.347
Conclusion	as $\alpha < p$-value, **there is no reason for rejecting hypothesis H_0** with statistical equality of average assessments	as $\alpha < p$-value, **there is no reason for rejecting hypothesis H_0** with statistical equality of average assessments	as $\alpha < p$-value, **there is no reason for rejecting hypothesis H_0** with statistical equality of average assessments

Table 11. Changes observed by the students - level of students' fatigue.

Level of students' fatigue in their own opinion		Average	N	Standard deviation	Conclusions on the basis of the average assessments
Pair 1	level of fatigue during morning lessons, **before** school quieting	3.10	378	1.147	level of fatigue during morning lessons before and after the school quieting was **at the same level**
	level of fatigue during morning lessons, **after** school quieting	3.14	378	1.225	
Pair 2	level of fatigue immediately before the lunch break, **before** school quieting	2.96	378	1.112	level of fatigue immediately before the lunch break before and after the school quieting was **at the same level**
	level of fatigue immediately before the lunch break, **after** school quieting	3.03	378	1.165	
Pair 3	level of fatigue during afternoon lessons, **before** school quieting	3.16	378	1.197	level of fatigue during afternoon lessons before and after the school quieting was **at the same level**
	level of fatigue during afternoon lessons, **after** school quieting	3.21	378	1.202	

The results in the table above indicate that there is no reason to reject H_0 hypothesis, therefore, changes in school acoustics did not affect students' fatigue in their opinion, they are equally tired in the three situations studied – during the morning lessons, before lunch breaks and during afternoon lessons, as before acoustic treatment of the school. The lack of confirmation of this fact in the children's opinion may also result from the difficulty of assessing this phenomenon, as the level of tiredness for children may be difficult to assess.

The analysis of the average results of assessments by the students in terms of the level of fatigue shows no statistical differences in the assessment of this phenomenon, so the level of fatigue of the students before and after the acoustic treatment remained the same in their opinion.

3.10. Teachers

The teachers presented a different evaluation of this phenomenon. The assessment of the student's fatigue level is presented in Tables 12 and 13.

The results in the table above indicate the basis for rejecting H_0 hypothesis and accepting hypothesis H_1 as true, i.e. the average results of the assessments (before and after the acoustic treatment) are statistically different in all three areas of the study – the level of student's fatigue during morning lessons, before the lunch break and during the afternoon lessons. The difference in the students' and teachers' assessments may result from the ability to assess the behaviour properly as a result of the teacher's experience, observation ability and knowledge.

The analysis of the average results of the assessments of the assigned teachers points to statistically higher assessments obtained after the acoustic treatment, which means that in the opinion of the teachers, the level of the students' fatigue is lower after the acoustic treatment of the school.

Differences in student fatigue level assessment are presented by Fig. 8.

The teachers' assessment in many areas was calibrated in a more precise way and concerned more specific issues. The students' performance was evaluated taking into account level of concertation, level of following, simple and complex teacher's instructions (Tables 14 and 15), pace of work (Fig. 9), short term memory capacity (Fig. 10), task fulfilment (Fig. 11) and level of aggression (Fig. 12).

Table 12. Wilcoxon rank test results – changes observed by the teachers – level of students' fatigue.

Level of students' fatigue	Level of students' fatigue during morning lessons, before and after school quieting	Level of students' fatigue before the lunch break, before and after school quieting	Level of students' fatigue during afternoon lessons, before and after school quieting
Z	–3.667	–3.487	–3.153
p-value	0.000	0.000	0.000
Conclusion	as $\alpha > p$-value, hypothesis H_0 is rejected and we **accept $\mathbf{H_1}$** as true	as $\alpha > p$-value, hypothesis H_0 is rejected and we **accept $\mathbf{H_1}$** as true	as $\alpha > p$-value, hypothesis H_0 is rejected and we **accept $\mathbf{H_1}$** as true

Table 13. Changes observed by the teachers – level of students' fatigue.

Level of students' fatigue in a teachers' opinion		Average assessment	N	Standard deviation	Conclusions on the basis of the value of average assessments
Pair 1	Level of students' fatigue during morning lessons, **before** school quieting	2.61	38	0.755	Level of students' fatigue during morning lessons **is lower after** school quieting
	Level of students' fatigue during morning lessons, **after** school quieting	3.37	38	0.852	
Pair 2	Level of students' fatigue before the lunch break, **before** school quieting	2.63	38	0.714	Level of students' fatigue before the lunch break **is lower after** school quieting
	Level of students' fatigue before the lunch break, **after** school quieting	3.29	38	0.654	
Pair 3	Level of students' fatigue during afternoon lessons **before** school quieting	2.15	39	0.961	Level of students' fatigue during afternoon lessons **is lower after** school quieting
	Level of students' fatigue during afternoon lessons **after** school quieting	2.85	39	0.709	

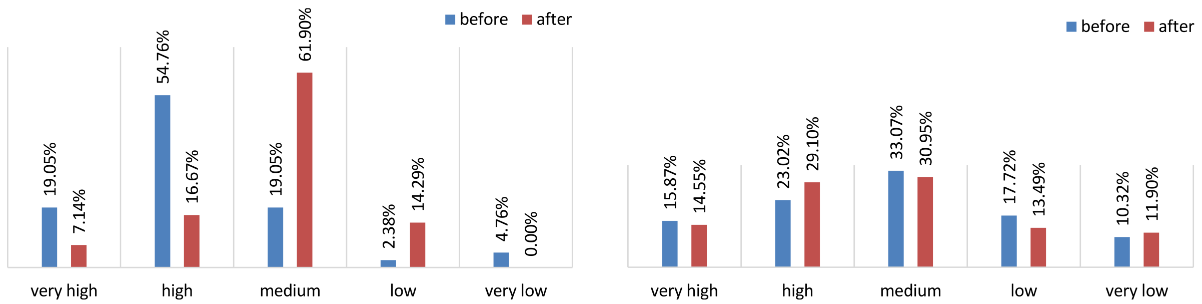

Fig. 8. Students' fatigue during afternoon lessons, assessment made by teachers (left) and students (right).

Table 14. Wilcoxon sign rank test results – changes observed by the teachers – student's independent work in the classroom.

Assessment of teachers	Level of a student's concertation, before and after school quieting	Level of following simple teacher's instructions, before and school quieting	Level of following complex teacher's instructions, before and after school quieting
Z	−5.289	−5.066	−5.291
p-value	0.00	0.00	0.00
Conclusion	as $\alpha > p$-value, hypothesis H_0 is rejected and we **accept H_1** as true	as $\alpha > p$-value, hypothesis H_0 is rejected and we **accept H_1** as true	as $\alpha > p$-value, hypothesis H_0 is rejected and we **accept H_1** as true

Table 15. Changes observed by the teachers – student's independent work in the classroom..

Changes in the independent work in the classroom – teacher's assessment		Average assessment[c]	N	Standard deviation	Conclusions on the basis of the value of average assessments
Pair 1	level of a student's concentration **before** school quieting	3.18	38	0.692	level of a student's concentration **is statistically higher** after school quieting
	level of a student's concentration **after** school silencing	2.16	38	0.547	
Pair 2	level of following simple teacher's instructions **before** school quieting	3.08	38	0.784	level of following simple teacher's instructions **is statistically higher** after school quieting
	level of following simple teacher's instructions **after** school quieting	2.08	38	0.632	
Pair 3	level of following complex teacher's instructions **before** school quieting	3.34	38	0.847	level of following complex teacher's instructions **is statistically higher after** school quieting
	level of following complex teacher's instructions **after** school quieting	2.34	38	0.669	

[c] The lower the average assessment given by the teachers, the better the result – according to the scale adopted in the survey.

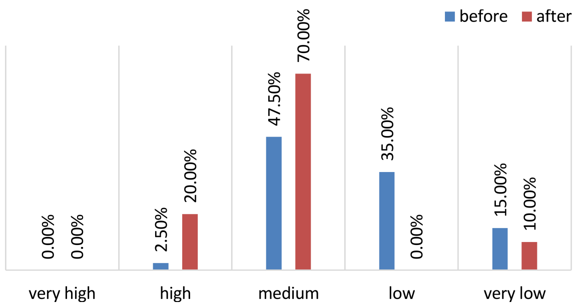

Fig. 9. Students' pace of work during afternoon lessons, assessment made by teachers.

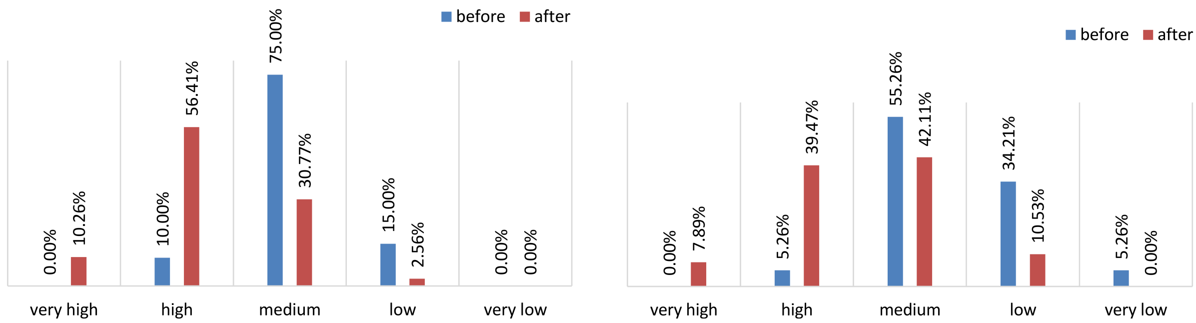

Fig. 10. Students' short term memory capacity, assessment made by teachers and concerning new content (left) and difficult content (right).

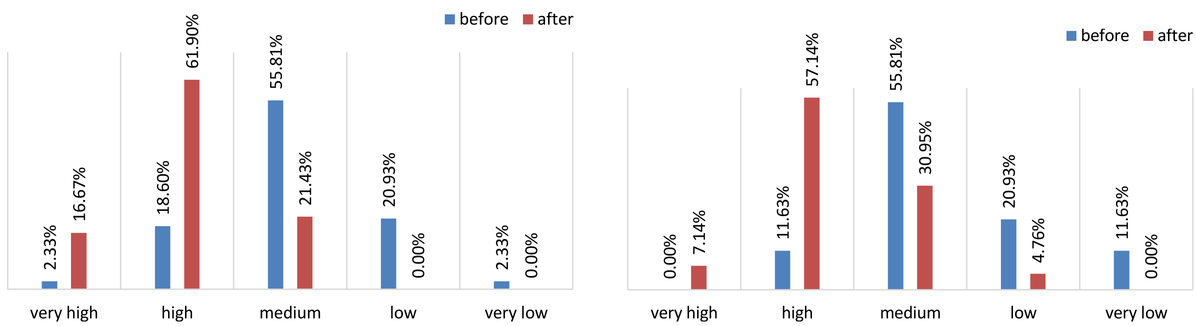

Fig. 11. Students' task fulfillment, assessment made by teachers for simple tasks (left) and complex ones (right).

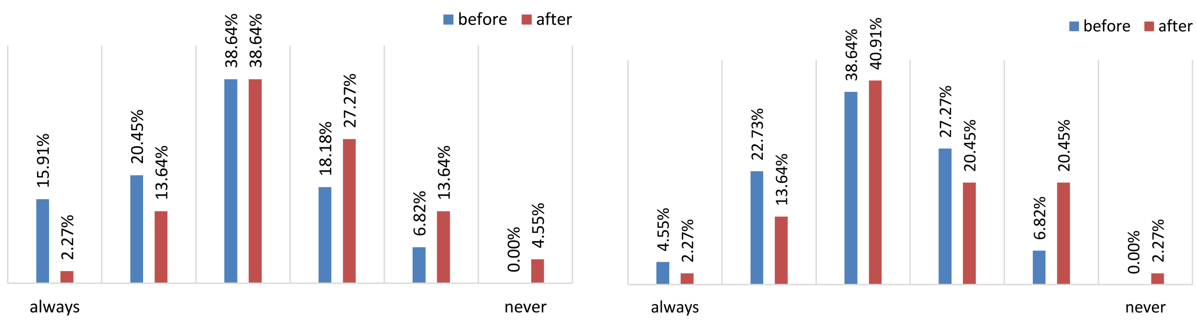

Fig. 12. Students' level of aggression during breaks in assessment of teachers: physical aggression (left) and mental aggression (right).

The results in the table above indicate the basis for rejecting H_0 hypothesis and accepting hypothesis H_1 as true, i.e. the average results of the teachers' assessments (before and after the acoustic treatment) are statistically different in all three areas of the study – student's level of concertation and level of following simple and complex teacher's instructions.

Table 15 presents the average results of assessments determined by the teachers for the identification of the direction of change.

The analysis of average results of the assessments given by the teachers' points to statistically higher grades obtained after the acoustic treatment in all three areas of the study – student's level of concentration and level of following simple and complex teacher's instructions. Therefore, the acoustic treatment of the school in the opinion of the teachers positively influenced their functioning in this area.

Presented above data are just a part of all collected during survey. The whole material shows following consequences of acoustic treatment of school premises.

Teachers asked about students' performance and behavior noticed positive changes in level of concentration and pace of work (both during individual and group work), task fulfillment, short term memory capacity, durability of memory, level of fatigue and aggression and above all level of speech intelligibility.

When asked about their working conditions they can see benefits in lower fatigue, lower voice effort, lower prevalence of hoarse, headache and tinnitus and lower level of stress.

4. Discussion

The presented research results are part of a comprehensive research material in the field of studying the impact of acoustic treatment of school interiors on functioning of the students and the teachers. The presented research material shows that the acoustic modernisation carried out at school resulted in the following changes:

1) Objective changes (measurements and calculations):
   - reverberation time in the classrooms has been basically limited to the level required by PN-B-02151-4: 2015-06 standard,
   - the averaged values of the STI speech transmission index for the classrooms increased from approx. 0.5 to approx. 0.7, significantly exceeding the minimum level specified in PN-B-02151-4: 2015-06 standard,
   - in after-school clubs, sport halls and canteen, the reverberation time has been limited to the level required by PN-B-02151-4: 2015-06 standard,
   - corridors and halls sound absorption has been multiplied and clearly exceeds the minimum level specified in PN-B-02151-4: 2015-06,
   - the largest reduction in the sound level was achieved in the canteen (approx. 10 dB), slightly lower in the corridors (approx. 9 dB) and the sport hall (approx. 7 dB) and the weakest effect was observed in the after-school clubs (approx. 6 dB).
2) Subjective changes (opinions of the students and the teachers):
   - Teachers' and students' answers were generally consistent: they reported that acoustic treatment brought improvement in almost every aspect of their performance and wellbeing in school. However, teachers pointed out much deeper changes that students did. For instance, level of students' concentration was rated as "high" or "very high" by 33.5% (before) and 65.8% (after) of students. In case of teachers' assessment it was respectively 16.3% and 78.6%.
   - It was just one area where students could not observe any change. It was level of their own fatigue. It is surprising, because teachers asked about that issue reported vast difference: level of students' fatigue during afternoon lessons was rated as "high" or "very high" by 73.8% (before) and 23.8% (after) of teachers.
   - Perceived changes in level of aggression among students were less evident than in case of other issues, although still clear. Prevalence of physical aggression during breaks was rated as "very often" or "often" by 36.4% (before) and 15.9% (after) of teachers.
   - Most appreciated by teachers change is better speech communication in classrooms and corridors. Students emphasise lower sound levels in this spaces.

5. Conclusion

The results of presented study indicate significant improvement of teachers' and students' performance and wellbeing after comprehensive acoustic treatment of school building. Positive changes were noticed in students' level of concentration, short memory capacity and pace of work. After acoustic treatment students (both in teachers' and their own opinion) can better hear and understand teachers' instructions and are much more capable of task fulfilling. Both teachers and students observed clear reduction of aggression level among students. This results strongly point to advisability of acoustic treatment undertaken in existing school buildings. Subsequent research results will be presented in later studies of the authors.

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