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Acoustics of Classrooms in Primary Schools – Results of the Reverberation Time and the Speech Transmission Index Assessments in Selected Buildings

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The article presents results of our own research regarding acoustic properties of 110 classrooms in five typical primary schools in Warsaw. The target of the research was to assess the classrooms using established criteria. These criteria include the reverberation time and the speech transmission index. The research has shown a large diversity of acoustic properties of classrooms within each of the schools and between the schools, resulting from the classroom equipment and the school building construction. In addition, the assessment has indicated that classrooms in schools researched do not meet the established acoustic criteria (reverberation time and speech transmission index). Because the classroom equipment is different for younger forms (integrated teaching) and for older forms (subject teaching), the results have been analyzed separately for rooms for younger forms (0–III) and for rooms for older forms (IV–VI). Synthetic results prove the advisability of such division. Correlation analysis has been conducted for the speech transmission index STI and reverberation time T_{mf}, as well as for the speech transmission index STI and the suggested reverberation time T_{wf} defined in a similar manner as T_{mf}, but in a wider frequency range. The correlation between the speech transmission index STI and T_{wf} is higher than that between the STI index and T_{mf}. The reverberation time T_{wf} can therefore be used for a more precise assessment of acoustic properties of interiors with regard to verbal communication than T_{mf}. In addition, the paper presents estimated analysis results of the influence of selected classroom equipment (carpets) on its acoustic properties.

Keywords: primary school noise, reverberation time, speech transmission index, STI.

1. Introduction

Clarity of speech in school rooms is influenced, among other factors, by their acoustic properties. These result from: room volume, its shape, properties of materials used to construct surfaces delimiting the room and its equipment (Mikulski, Radosz, 2009). Depending on the intended use (in schools: classrooms, corridors, canteens, etc.), they have to meet different requirements, including those related to acoustics (Koszarny, Chyla, 2003). The research discussed in this paper covered acoustic properties of rooms used to conduct classes in primary schools.

Acoustic properties of rooms can be described using the following parameters (Engel *et al.,* 2007): reverberation times (T_{20}, T_{30}, T_{mf}), early decay time (EDT), speech transmission index (STI), percentage articulation loss of consonants (%ALC), clarity index (C_{50}), clarity (D_{50}), lateral energy fraction (LF), etc. Because the parameters commonly used to assess acoustic properties of classrooms in primary schools, with regard to verbal content communication, include the reverberation time T_{mf} and speech transmission index STI, the article presents results for these two parameters assessed in 110 classrooms in 5 primary schools in Warsaw selected from a set of 100. Literature data and our own research results indicate that acorrelation between the reverberation time T_{mf} and the speech transmission index STI not always exists (Augustyńska *et al.*, 2010). It is obvious in cases when the aural perception process is influenced by the acoustic background (Rudno–Rudzińska, Czajkowska, 2010; Kotus *et al.*, 2010). However, according to the authors, even in cases when the acoustic background is negligible, the correlation between T_{mf} and STI is not satisfactory. Therefore, a new parameter to measure reverberation time has been defined and assessed. In addition, its correlation with STI has been analyzed. Classroom equipment influences acoustic properties of a room (its acoustic absorption), therefore it plays a significant role with regard to speech clarity (Sato, Bradley, 2008). Therefore, an experiment has been conducted to assess the influence of extra classroom equipment (a carpet) on the reverberation time and the speech transmission index.

2. Characteristics of assessed classrooms

The assessment has been conducted using measurement methods in primary school classrooms in Warsaw. It has been assumed that the measurements would be conducted in all classrooms of five typical schools out of a group of 100 primary schools in Warsaw. Preliminary information obtained from the administration of primary schools in Warsaw indicated that the rooms have different volumes (which influences e.g. the reverberation time), it has been assumed that the 5 schools selected for the assessment would have rooms of different sizes.

The distribution of average classroom volumes in 100 primary schools in Warsaw has two maxima: 160 m^3 (about 76%) and 190 m^3 (about 12%). Therefore, the measurements have been conducted in three schools with an average room volume of about 160 m^3 and in two schools with an average room volume of about

190 m^3. In order to enhance the distribution of samples, buildings commissioned in various years have been selected (to assess the influence of construction and decoration of schools on room acoustics), taking the into account the distribution of the number of school buildings commissioned in various years. Basing on criteria established in such a way, 5 primary schools have been chosen: A (commissioning year: 1793, average classroom volume $V_{\text{mean}} = 160$ m^3), B (2003; $V_{\text{mean}} = 194$ m^3), C (1993; $V_{\text{mean}} = 190$ m^3), D (1981; $V_{\text{mean}} = 157$ m^3) and E (1973; $V_{\text{mean}} = 161$ m^3) (the order of school symbols reflects the order of the measurements).

Schools chosen for measurements also differed in: size (cubature), room layout, number of classrooms, decoration, equipment, location within the external environment and the number of students. Considering the properties of classrooms with regard to their influence on clarity of verbally communicated content, the classrooms have been divided into 2 groups:

- group one: rooms for classes 0–III, including two subgroups: zero-grade rooms and rooms for education of grades I–III,
- group two: rooms for classes IV–VI, including rooms for education of older pupils – grades IV–VI.

Group one – the zero-grade classroom subgroup

Decoration and equipment of zero-grade classrooms is midway between common rooms and grade I–III classrooms. In most cases, zero-grade rooms feature carpet lining. Because of the large amount of equipment, these rooms are characterized by the greatest acoustic absorption of all classrooms. Because the intended use of all zero-grade classrooms is the same, not much diversity of acoustic parameters of individual classrooms was expected in this subgroup (homogenous subgroup).

Group one – the grade I–III classroom subgroup

In grade I–II classrooms, integrated subject classes are taught, and because the individual classes (groups of students) do not change rooms, their equipment is also relatively rich; however, it is more sparse than in zero-grade classrooms. Thus, classrooms for grades I–III are expected to have slightly higher reverberation time values than zero-grade classrooms. Because the intended use of all grade I–III classrooms is the same, no significant acoustic parameter diversity characterizing individual classrooms was expected in this subgroup too (homogenous subgroup).

Because of similar equipment, both these subgroups were analyzed as one group – form 0–III classrooms.

Group two – form IV–VI classrooms

In classrooms dedicated for grades IV–VI, individual subjects are taught; therefore, they feature equipment for teaching various subjects (e.g. nature, mathematics). This equipment is significantly sparser than in the zero-grade or grade I–III classrooms. Because of that, form IV–VI classrooms were expected to feature longer reverberation times than form 0–III classrooms. Form IV–VI classrooms have more diverse equipment; therefore, the highest diversity of acoustic property parameter values was expected in these classrooms, as opposed to form 0–III classrooms. Form IV–VI classrooms differ greatly with respect to equipment; therefore, the greatest diversity of acoustic property parameter values of individual classrooms was expected. Considering the subjects taught, this group could be divided into subgroups containing classrooms used to teach: languages (Polish, English, Russian or other), history, mathematics, physics, natural sciences, music, etc. However, such division is unjustified with respect to acoustics since acoustic properties depend on the amount of equipment (bookcases, showcases, shelves, didactic tools, additional information boards), but not on the subject taught. Therefore, rooms used to teach foreign languages do not need to be considered separately when assessing acoustics. In some countries, more stringent criteria are used to evaluate foreign language classrooms, which may justify their separate consideration. In the research conducted, these classrooms were not evaluated separately.

Rooms used for special teaching, which is usually an individual teaching (e.g. speech therapy rooms, compensation teaching rooms), constitute a separate group of classrooms. Such rooms (usually not numerous) are significantly smaller than standard classrooms due to the profile of classes taught. This last group of special rooms, characterized by the best acoustic properties, was not considered.

3. Applied research methods and classroom evaluation criteria

3.1. Applied classroom acoustic property evaluation parameters

The speech transmission index STI and reverberation time T_{mf} (according to the Building Bulletin 93 – arithmetic mean of reverberation times for 500 Hz, 1000 Hz, 2000 Hz frequencies) were used to evaluate the acoustic properties of classrooms. The reverberation time T_{mf} measurement results do not always reflect subjective evaluation of acoustic properties of rooms and the speech transmission index STI even with low acoustic background (Mikulski, Radosz, 2009). Therefore, an additional parameter T_{wf} to characterize the reverberation time was defined and included in the conducted research (Mikulski, Radosz, 2010). It is defined, in seconds, as the arithmetic mean of reverberation time for

250 Hz, 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz frequencies, using the following formula:

$$T_{mf} = \frac{1}{3} \sum_{f=500\ \text{Hz}}^{2000\ \text{Hz}} T_f, \tag{1}$$

where T_f – reverberation time in octave frequency band f, in seconds, f – median frequencies of octave frequency bands {500 Hz, 1000 Hz, 2000 Hz}.

$$T_{wf} = \frac{1}{5} \sum_{f=250\ \text{Hz}}^{4000\ \text{Hz}} T_f, \tag{2}$$

where T_f – reverberation timein octave frequency band f, in seconds, f – median frequencies of octave frequency bands {250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz}.

3.2. The measurement method

The problem considered is the determination of acoustic properties of primary school classrooms using the reverberation time (T_{mf}, T_{wf}) and the speech transmission index (STI).

The aim of the research was to assess whether the acoustic properties of classrooms meet the assumed criteria.

Measurements were performed in classrooms with equipment, but with no people. The impulse method was applied, using a pseudo-random MLS signal (EN ISO 3382-2:2008).

To obtain the T_{mf} and T_{wf} parameters the reverberation time T_{30} was derived from impulse responses processing.

When STI is obtained from measurements using MLS, the background noise in the actual measurement is automatically taken into account when computing the modulation transfer function (MTF), the modulation transfer index (MTI) and speech transmission indices. A calibrated source is required to obtain the speech spectrum and level. STI can also be obtained using results of measurements of the general impulse response and manually adding background noise and speech levels. It is preferred to measure the room properties and background noise separately because the measurement of the room impulse response is impacted negatively by high background noise levels. The authors choose to obtain STI by measuring impulse response without background noise in order to get the optimum impulse response to noise ratio (INR) and because there is no specification of standards or guidelines for background noise in classrooms at which this parameter should be measured or calculated. The SNR during measurements was higher than 15 dB in each octave band. The following equipment was used for the measurements: Alesis IO2 audio interface, B&K 4939 microphone, B&K NEXUS microphone preamplifier, B&K 4296 omnidirectional source with amplifier and the WINMLS software. The directivity of the sound source has an impact on STI only if the background noise in the actual measurement is automatically taken into account (SNR below 15 dB) (Radosz, Mikulski, 2011). It was not necessary to use another sound source with directivity similar to a human talker (e.g. a mouth simulator) during the measurements. Measurements in each room were conducted in two measure points, and the mean value was computed for each pair.

The measurements were performed at least three times in each measurement point and the mean value was computed. When the relative difference of the maximum and minimum values from 3 reverberation time T_{mf} measurements divided by the minimum value, was greater than 5%, 5 measurements were performed. When the difference from 5 measurements was greater than 5%, 10 measurements were performed.

The speaker was located in the place where the teacher is usually located (desk near the corner of the room, near the window). The first measurement point was placed where the student closest to the teacher is located. The second point was placed, where the student furthest from the teacher is usually located.

3.3. Classroom evaluation criteria

Until now, no official criteria for acoustic evaluation of classrooms exist in Poland. Selected admissible values for reverberation time and the speech transmission index STI in selected countries have been shown in Table 1.

Table 1. Admissible values of reverberation time and the speech transmission index (STI) in primary school classrooms.

Country	Document	Reverberation time [s]	STI
France	Decree 1995	0.4–0.8	–
Netherlands	Guidelines NEN 5077	0.8	–
Sweden	Standard SS025268	0.5–0.6	–
Norway	Standard NS 8175	0.6	–
Portugal	NBR 12179, 1992	0.6–0.8 (250–4000 Hz) 1 (125–250 Hz)	–
USA	Standard ANSI S.12.60	$T_{mf} < 0.6$ (< 283 m^3) $T_{mf} < 0.7$ (> 283 m^3 and ≤ 566 m^3)	–
Great Britain	Guidelines BB93	$T_{mf} < 0.6$ primary schools $T_{mf} < 0.8$ secondary schools	STI ≥ 0.6
Australia and New Zealand	Standard AS/NZS 2107	$T_{mf} < 0.4$–0.5	–
Finland	Standard SFS 5907:en	0.6–0.8 (250–4000 Hz) 50% higher for 125 Hz	Classes A, B: STI ≥ 0.8 Class C: STI ≥ 0.7

Table 2 presents the the ranges values of of the speech transmission index STI and the corresponding subjective speech clarity evaluation.

Table 2. Ranges of the speech transmission index STI values and the corresponding subjective speech clarity evaluation.

STI	0–0.3	0.3–0.45	0.45–0.6	0.60–0.75	0.75–1.0
Subjective speech clarity evaluation	unintelligible	poor	fair	good	excellent

Currently, the Polish Standard prPN-B-02151-4 is under development (Technical requirements, 2009, p. 241). It will provide optimum values of the reverberation time in octave frequency bands in classrooms and schools. These values depend on the room volume (Table 3).

Table 3. Recommended values of reverberation time T in classrooms (according to prPN-B-02151-4 Polish standard draft).

Room type	Optimum reverberation time T_{opt} [s]	Tolerance range for reverberation time T
Classrooms with volume $V = 30$–$1000\ \text{m}^3$	$T_{\text{opt}} = 0.32 \cdot \lg(V) - 0.17$	• $0.65\ T_{\text{opt}} < T < 1.2T_{\text{opt}}$ (for 125 and 4000 Hz bands) • $0.8\ T_{\text{opt}} < T < 1.2T_{\text{opt}}$ (for 250, 500, 1000 and 2000 Hz bands)

The draft of this standard provides the admissible range for the reverberation time tolerance (defined using the $T_{\text{min,dop}}$ and $T_{\text{max,dop}}$ values in this paper). The authors did not expect (as proven by research results) that classrooms may feature reverberation times lower than $T_{\text{min,dop}}$. This means that rooms conform to evaluation criteria according to the aforementioned standard if the measured reverberation time value is lower than the maximum admissible reverberation time value $T_{\text{max,dop}}$. The maximum admissible reverberation time is defined in seconds using the following formula (based on prPN-B-02151-4, taking into account the upper bound of tolerance):

$$T_{\text{max,dop}} = 1.2 \cdot [0.32 \cdot \lg(V) - 0.17], \tag{3}$$

where V – room volume, in m^3.

The admissible values of reverberation times T_{mf} and T_{wf} will be the same due to the range of frequencies used to determine the reverberation times T_{mf} and T_{wf} and the fact that the admissible value pertains to the maximum (upper 20% tolerance value, resulting from coefficient 1.2 in Table 3). As most considered classrooms have a volume of around 160 m^3 (76%), it was assumed for simplicity that the maximum reverberation time of both parameters is 0.65 s, i.e.:

$$T_{\text{max,dop}}(160\ \text{m}^3) = 0.65\ \text{s}.$$

No minimum admissible values of the speech transmission index STI has been defined for classrooms in Poland. The authors have assumed that speech clarity in primary school classrooms (where children are taught) should be at least "good". In the currently used criteria, defined using research conducted on adults, "good" refers to the speech transmission index value STI ≥ 0.6 (Table 2). Bradley and Sato (2008) claim that children attending classes in primary schools, learning new words and terms, have significantly lower speech understandability than adults; therefore, the authors have assumed a minimum speech transmission index value $\mathrm{STI}_{\mathrm{dop}} = 0.70$ (similarly to the value defined for class C classrooms in the Finnish standard SFS 5907:en, Table 3).

4. Measurement results and evaluation of classroom acoustic properties

Table 4 presents separately for form 0–III classrooms and form IV–VI classrooms and for each primary school (A, B, C, D, E): the number of classrooms, mean room volume in the school, mean reverberation times $T_{mf,\mathrm{mean}}$ and $T_{wf,\mathrm{mean}}$ of rooms in the school including standard deviation. Table 5 presents separately for form 0–III classrooms and for form IV–VI classrooms the mean values of reverberation times $T_{mf,\mathrm{mean,all}}$ and $T_{wf,\mathrm{mean,all}}$ in all schools.

Figures 1 and 2 show measurement results for reverberation times T_{mf} and T_{wf} (x axis – room volume V) in classrooms (one marker represents measurement result of one parameter in a single classroom). Form 0–III rooms have been plotted with white-filled markers, form IV–VI classrooms black-filled markers have been used.

The synthetic results provide sample results for the reverberation time T_{wf}, as this parameter was assumed most appropriate for the determination of acoustic properties of classrooms – see Sec. 5. The mean reverberation times ($T_{wf,\mathrm{mean,all}}$) from all schools (Table 5) are as follows: form 0–III classrooms – 1.03 s, form IV–VI classrooms – 1.20 s, which confirms the assumption that form 0–III classrooms feature higher acoustic absorption, as their equipment is different than that in form IV–VI classrooms. When comparing the mean reverberation time values ($T_{mf,\mathrm{mean}}$, $T_{wf,\mathrm{mean}}$) in individual schools (Table 4), separately in the form 0–III classroom and form IV–VI classroom groups, the high diversity of this parameter values between schools can be observed (form 0–III classrooms – 0.87 s, 0.93 s, 0.94 s, 1.12 s, 1.30 s, form IV–VI classrooms – 1.07 s, 1.15 s, 1.17 s, 1.24 s, 1.31 s), which is caused by different classroom equipments and differences in the building construction. Distribution of the T_{mf} and T_{wf} reverberation time values in classrooms in all schools (Fig. 3 and 4), with division into form 0–III and form IV–VI classrooms, shows that these parameters differ significantly between individual classrooms. It can be noted that in most classrooms the reverberation times T_{wf} equals: form 0–III classrooms III – 0.95 s ± 0.1 s (43% cases), form IV–VI – 1.15 s ± 0.1 s (34% cases).

Table 4. Mean values of reverberation time ($T_{mf,\mathrm{mean}}$, $T_{wf,\mathrm{mean}}$) and the speech transmission index $\mathrm{STI}_{\mathrm{mean}}$ in classrooms in researched schools.

School	Classroom	n	V_{mean} [m^3]	$T_{mf,\mathrm{mean}}$ ($T_{mf,\mathrm{min}}$–$T_{mf,\mathrm{max}}$) [s]	$\mathrm{SD}_{T_{mf}}$	$T_{wf,\mathrm{mean}}$ ($T_{wf,\mathrm{min}}$–$T_{wf,\mathrm{max}}$) [s]	$\mathrm{SD}_{T_{wf}}$	$\mathrm{STI}_{\mathrm{mean}}$ ($\mathrm{STI}_{\mathrm{min}}$–$\mathrm{STI}_{\mathrm{max}}$)	$\mathrm{SD}_{\mathrm{STI}}$
A	0–III	7	161.3	0.87 (0.59–1.09)	0.18	0.87 (0.60–1.06)	0.16	0.68 (0.63–0.74)	0.04
	IV–VI	13	160.0	1.19 (0.79–1.58)	0.23	1.17 (0.79–1.51)	0.22	0.62 (0.56–0.69)	0.04
B	0–III	13	198.6	1.08 (0.89–1.19)	0.10	1.12 (0.91–1.25)	0.11	0.61 (0.59–0.66)	0.02
	IV–VI	16	190.8	1.15 (0.85–1.42)	0.19	1.24 (0.90–1.54)	0.21	0.59 (0.55–0.65)	0.03
C	0–III	5	189.7	1.35 (1.29–1.45)	0.06	1.30 (1.26–1.39)	0.05	0.57 (0.56–0.59)	0.01
	IV–VI	18	190.0	1.35 (0.86–1.71)	0.24	1.31 (0.86–1.64)	0.23	0.57 (0.53–0.65)	0.04
D	0–III	5	156.9	0.97 (0.75–1.23)	0.19	0.93 (0.76–1.14)	0.16	0.66 (0.61–0.72)	0.05
	IV–VI	12	161.7	1.11 (0.97–1.27)	0.10	1.07 (0.93–1.24)	0.10	0.63 (0.60–0.67)	0.02
E	0–III	12	160.8	0.94 (0.83–1.06)	0.08	0.94 (0.82–1.05)	0.08	0.63 (0.61–0.68)	0.02
	IV–VI	9	161.3	1.18 (1.08–1.37)	0.09	1.15 (1.05–1.32)	0.09	0.59 (0.57–0.63)	0.02

n – number of classrooms,
V_{mean} – mean valueof volume of the classrooms, in m^3,
$T_{mf,\mathrm{mean}}$ – mean value of mid-frequency reverberation time in classrooms, in s,
$T_{wf,\mathrm{mean}}$ – mean value of wide-frequency reverberation time in classrooms, in s,
$\mathrm{STI}_{\mathrm{mean}}$ – mean value of speech transmission index in classrooms,
$\mathrm{SD}_{T_{mf}}$ – standard deviation of T_{mf} in classrooms, in s,
$\mathrm{SD}_{T_{wf}}$ – standard deviation of T_{wf} in classrooms, in s,
$\mathrm{SD}_{\mathrm{STI}}$ – standard deviation of STI in classrooms.

Table 5. Mean values of reverberation times $T_{mf,\text{mean,all}}$, $T_{wf,\text{mean,all}}$ of all classrooms in researched schools.

	$T_{mf,\text{mean,all}}$ [s]	$T_{wf,\text{mean,all}}$ [s]
Form 0–III	1.03	1.02
Form IV–VI	1.21	1.20
Total	1.14	1.13

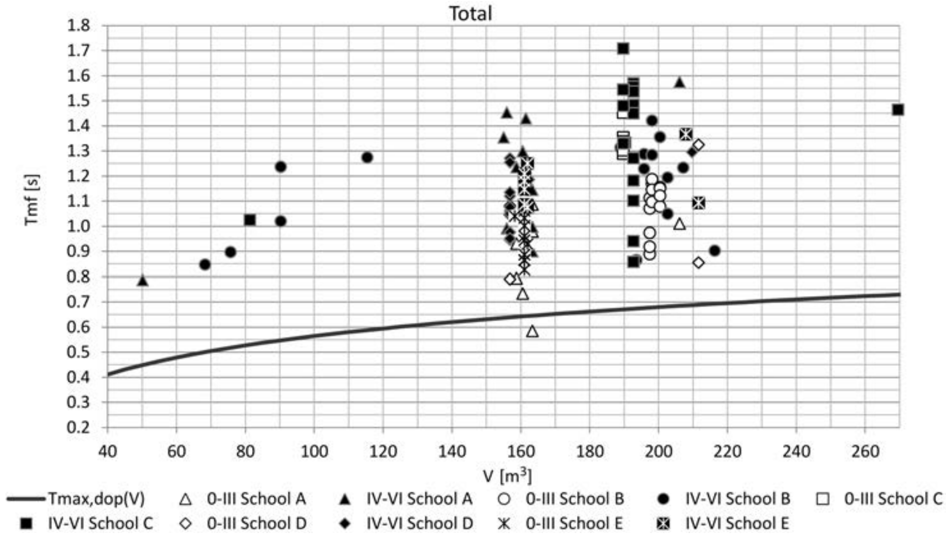

Fig. 1. Measurement results for reverberation time T_{mf} and classroom volume V.

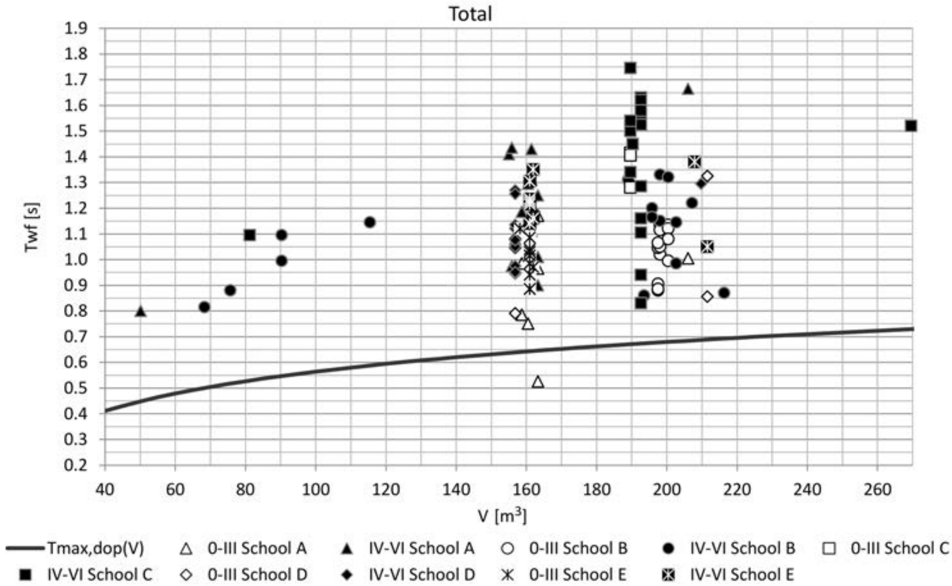

Fig. 2. Measurement results for reverberation time T_{wf} and classroom volume V.

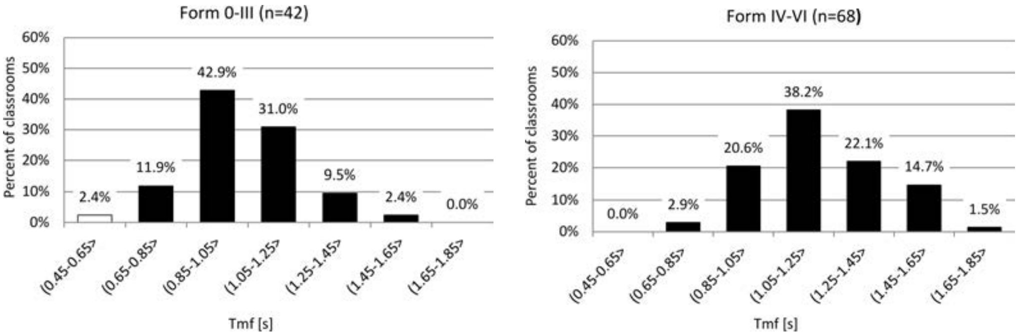

Fig. 3. Distribution of reverberation time T_{mf} values in classrooms in all schools divided into form 0–III and IV–VI (□ – values fulfilling the evaluation criteria).

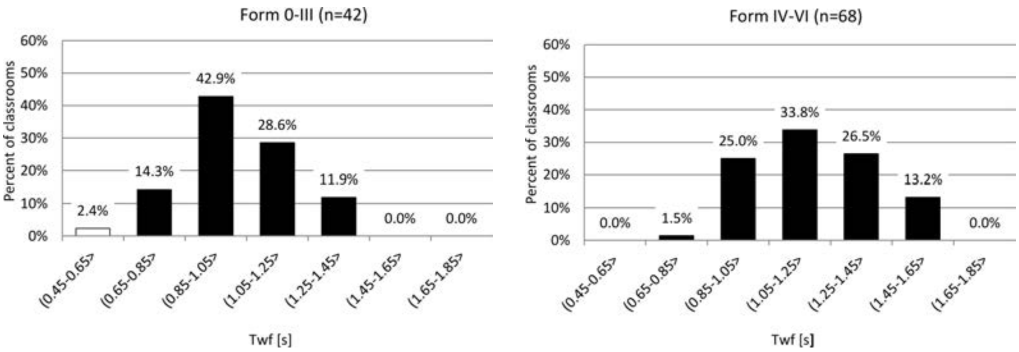

Fig. 4. Distribution of reverberation time T_{wf} values in classrooms in all schools divided into form 0–III and IV–VI (□ – values fulfilling the evaluation criteria).

When evaluating the quality of classrooms according to the criterion related to the T_{mf} and T_{wf} reverberation times (fulfilled for T_{mf} and $T_{wf} \leq 0.65$ s), it can be said that only in one classroom in school A this criterionis fulfilled (i.e. 0.9% of evaluated classrooms in all schools or 2.4% form 0–III classrooms an 0% form IV–VI classrooms in school A).

Figure 5 presents, for each classroom in the evaluated schools: the speech transmission index STI values (the x axis represents the volume of classrooms). Form 0–III classrooms have been plotted with white-filled markers;for form IV–VI classrooms black-filled markers have been used (one marker represents the measurement of one parameter in a single classroom). Table 6 presents, separately for form 0–III and form IV–VI classrooms, the mean values of the speech transmission index $\mathrm{STI}_{\mathrm{mean,all}}$ for all schools.

The mean speech transmission index $\mathrm{STI}_{\mathrm{mean,all}}$ from all schools (Table 6) equals: for form 0–III classrooms – 0.63, for form IV–VI classrooms – 0.60, which confirms the assumption that form 0–III classrooms feature a higher acoustic absorption resulting from the fact they contain more equipment than form IV–VI classrooms. When comparing the mean speech transmission index values $\mathrm{STI}_{\mathrm{mean}}$

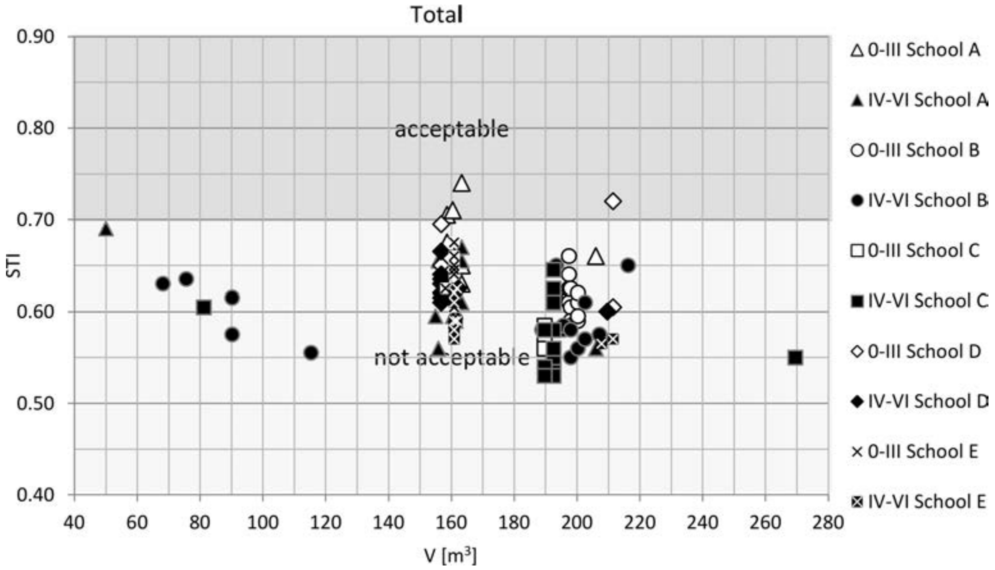

Fig. 5. Measurement results of the speech transmission index STI and volume V for classrooms in all schools.

Table 6. Mean values of the speech transmission index from all classrooms in the evaluated schools.

	$\text{STI}_{mean,all}$
Form 0–III	0.63
Form IV–VI	0.60
Total	0.61

in the individual schools (Table 4), separately in the form 0–III classroom and the form IV–VI classroom groups, a high diversity of this parameter values between schools can be observed (speech transmission index STI: form 0–III classrooms – 0.57, 0.61, 0.63, 0.66, 0.68, form IV–VI classrooms – 0.57, 0.59, 0,59, 0.62, 0.63), which is caused by different classroom equipment and differences in the building construction. The distribution of the speech transmission index STI values in classrooms in all schools (Fig. 6), with division into form 0–III and form IV–VI classrooms, shows that these parameters differ significantly between individual classrooms. It can be noted that in most classrooms the speech transmission index remain in the ranges: form 0–III classrooms – 0.60–0.65 (48% cases), form IV–VI – 0.55–0.60 (41% cases).

Figure 6 presents the distribution of the speech transmission index STI in classrooms in all schools, divided into form 0–III classrooms and form IV–VI classrooms.

When evaluating the quality of classrooms according to the criterion related to the speech transmission index STI (fulfilled for STI $\geq$ 0.70), it can be said

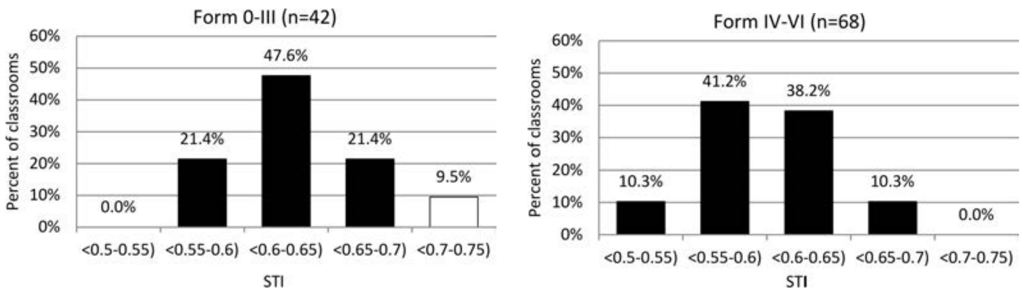

Fig. 6. Distribution of the speech transmission index STI in classrooms in all schools, for form 0–III and IV–VI classrooms separately (□ – values fulfilling evaluation criteria).

that in 4.5% of all evaluated classrooms the speech clarity fulfills this criterion; in other classrooms, the criterion is not met (i.e. 9.5% form 0–III classrooms and 0% form IV–VI classrooms). When evaluating the speech clarity in classrooms in individual schools, it can be said that it is appropriate: in school A – in 2.7% classrooms, in school D – in 1.8% classrooms; in other classrooms in schools A and D and in schools B, C and E, it is inappropriate.

The diversity of reverberation time values and the speech transmission index STI between classrooms again proves that it is caused by room equipment and the school building decoration (e.g. using wood panels, wall mats, etc.). This can be observed by comparing the measurement results for school C and for other schools. This was caused by the fact that the measurements took place when the building was being prepared for renovation and almost all equipment had been removed from the classrooms.

5. Comparison of measurement results the reverberation time and speech transmission index

Figure 7 shows for all evaluated classrooms in primary schools: the reverberation times T_{mf} and T_{wf} (x axis) and the speech transmission index STI (y axis). The measurement results confirm the well-known dependency that the reverberation time T_{mf} is inversely proportional to the speech transmission index STI.

The subjective evaluation of speech clarity and the speech transmission index STI do not always match the values of the commonly used reverberation time T_{mf} parameter. Therefore, Table 7 presents the calculated Pearson correlation value of the speech transmission index STI and reverberation times T_{mf} and T_{wf} in the evaluated classrooms.

The graphs and Table 7 show that the correlation is higher between the speech transmission index STI and the reverberation time T_{wf}, than between the index STI and the reverberation time T_{mf}. Therefore, it can be stated that the reverberation time T_{wf} provides a more precise evaluation of classrooms than the commonly used T_{mf} if the speech transmission index STI is unknown.

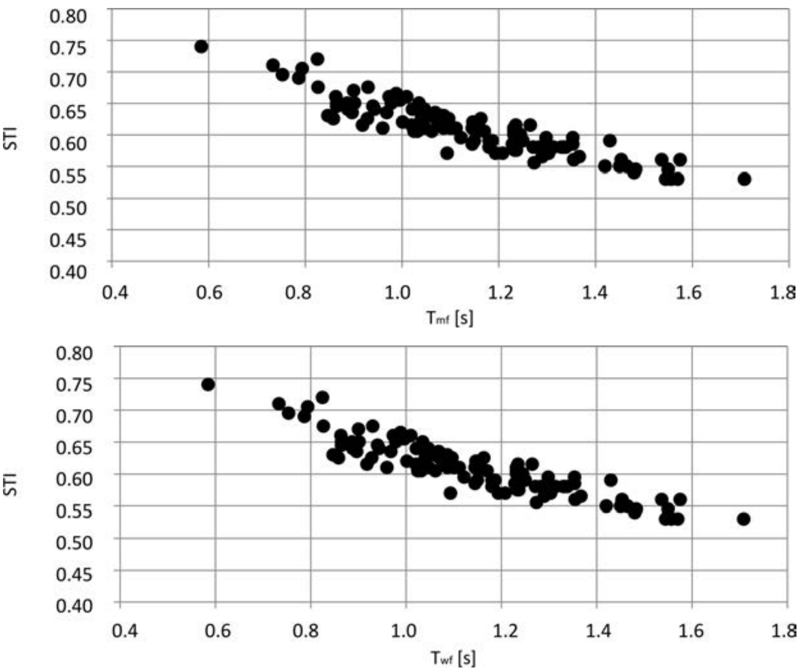

Fig. 7. Speech transmission index STI and reverberation times T_{mf} and T_{wf} in evaluated classrooms.

Table 7. Pearson correlation value of speech transmission index STI and reverberation times T_{mf} and T_{wf} in evaluated classrooms.

	T_{mf} and STI	T_{wf} and STI
Pearson correlation ($p < 0.05$)	−0.908	−0.917

6. Influence of classroom equipment changes on acoustic properties

The influence on the construction trim and room equipment on the reverberation time and the speech transmission index is commonly known; therefore, it will not be discussed here. The authors would like to point out the fact that using very simple and relatively inexpensive methods the clarity of communicated verbal content can be improved and thus enhancethe quality of education in primary schools. This section presents the results of an experiment consisting in a change of classroom equipment and its influence on the acoustic properties.

Figure 8 presents the influence of carpets of various areas (6 m^2 and 20 m^2) on the acoustic properties of a standard classroom (reverberation time and speech transmission index).

The results of the experimentsconducted show asignificant influence of thecarpet and its size on the reverberation time and the speech transmission index.

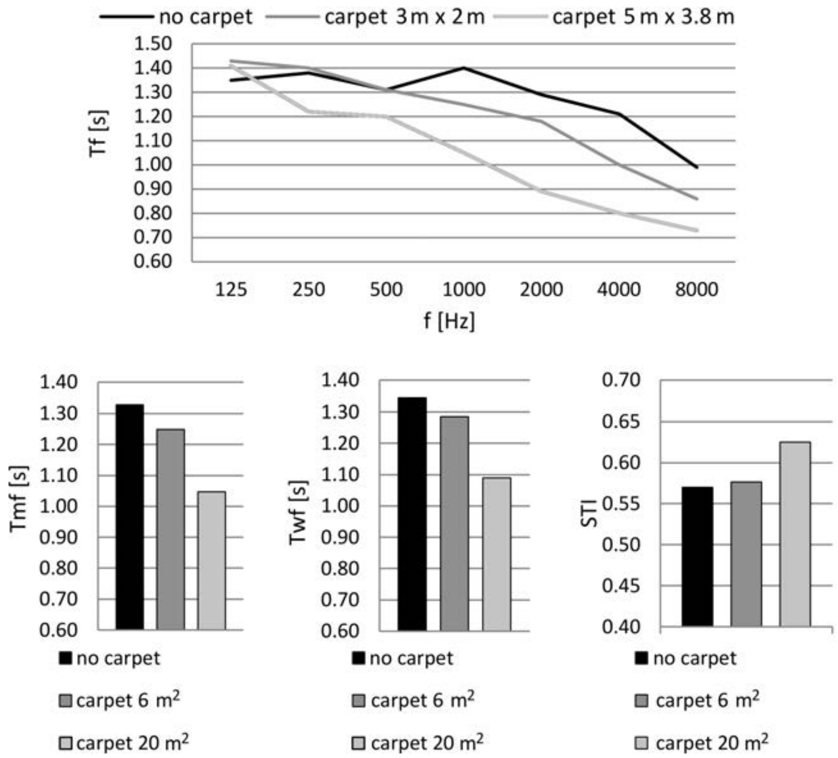

Fig. 8. Influence of carpets on the reverberation time and the speech transmission index in a standard classroom.

In the extreme case, i.e. for a room with a large carpet (20 m^2) and with no carpet, the reverberation time differs by 25%, and the speech transmission index – by 0.05. This result should be treated as an incentive to the use of carpets in classrooms in order to improve the speech clarity and the quality of education.

7. Conclusions

Basing on measurements conducted in 110 classrooms in 5 typical primary schools (out of a group of 100) in Warsaw, it can be concluded that:

- the Pearson correlation value between the speech transmission index STI and the reverberation time T_{wf} in evaluated classrooms is higher than between the STI index and the reverberation time T_{mf}. Therefore, the reverberation time T_{wf} (a new index, proposed by the authors of this paper, defined as the mean of the reverberation time values in octave frequency bands in the range of 250–4000 Hz) is more appropriate for the acoustic evaluation of classrooms with regard to the speech clarity than the reverberation time T_{mf},

- the mean reverberation time values and mean speech transmission index values in classrooms in various schools, as well as the reverberation time values and speech transmission index values in various classrooms in a given school show a high diversity. This is caused by the diverse classroom equipment and the construction differences between school buildings,
- classrooms, with regard to acoustic properties, can be divided into two groups (resulting from diverse equipment of classrooms): those with a shorter reverberation time (classrooms for teaching of younger forms 0–III) and those with a longer reverberation time (classrooms for teaching of older forms IV–VI),
- there is a need to adapt existing primary school classrooms in order to decrease noise arduousness and enhance speech clarity, as most classrooms do not meet the assumed criteria (the reverberation time criterion is met by 1 classroom; the speech transmission index criterion is met by 5 classrooms out of 110 evaluated typical schools in Warsaw),
- a significant improvement of acoustic properties of classrooms is possible by increasing the amount of equipment, e.g. by using carpet lining (the conducted experiment showed that introduction of a 20 m^2 carpet decreases the reverberation time by 25%),
- the typical volume of classrooms in primary schools in Warsaw is about 160 m^3.

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