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ACOUSTIC DESIGN OF EDUCATIONAL SPACES IN HUNGARY – A RETROSPECTIVE

Andor T. Fürjes*
aQrate Acoustics Ltd., Hungary 8083 Csákvár

ABSTRACT

Room acoustic design got support from a national standard only from 2020 in Hungary. This does not mean however, that there were no attempts to make clear to everyone, that acoustic comfort is a main concern in educational facilities.
The author looks into practical issues related to acoustic design of educational projects of the last decade, before and after the national standard was born. This includes design procedures, setting requirements, how the standard developed, how the standard works where it needs further development.
A part of the review is to show actual projects and measurement results, suggestions on how to improve current practices including setting requirements and to complete the engineering cycle by control measurements and communicating acoustic awareness.

Keywords: *room acoustics, educational facilities, measurement results, design procedure, project management.*

1. INTRODUCTION

Acoustic quality of educational facilities in Hungary is very diverse. New buildings are designed to comply current recommendations and standards. However, there is no government intention to improve acoustic conditions alone and existing buildings are rarely renovated beyond energetic and visual considerations. This does not necessarily mean that all educational spaces are unacceptable by today standards.
Sound isolation and noise level requirements are practically unchanged since 2007, but updating acoustic requirements became a hot topic only while discussing room acoustic requirements for the national standard MSZ 2080 [1]. After years of meetings, this standard got published in 2020.
To support a more moderate requirement setting, the author did a survey in local schools built >20 years before. In the authors practice, it only happened twice that the school required acoustic measurements after construction. Fortunately, educational staff and management are usually open for cooperation, so the author could measure some other newly built schools as well for his own interest.
The paper is a review of current acoustic requirements of educational facilities in Hungary with suggestions supported by measurement results and experience shared by teachers.

2. BACKGROUND

2.1 Acoustic requirements of educational facilities in Hungary

2.1.1 Comfort noise level requirement

Comfort noise level requirement for classrooms, lecture halls, playing and sleeping rooms for nurseries and kindergarten is set to 40 dB L_{AM} according to the relevant decree [2]. Here L_{AM} is the total spatially averaged level $L_{Aeq,T}$ (T during daytime 06-22h is 8 h of the noisiest period) with added corrections of impulsive or tonal attributes.
Somewhat contradictory, the MSZ 15601-2 [3] standard sets a 40 dB $L_{Aeq,T}$ requirement for traffic noise intrusion only. Other than that, there are no national standards or regulations for comfort noise levels, and the current practice is to set noise level requirements based on recommendations for other types of sources (e.g. the EN 16798-1 [4] for HVAC) or other types of rooms (e.g. the BB93 [5]).

* ***Corresponding author***: *furjes.andor@aqrate.hu*

2.1.2 Comfort vibration level requirement

Comfort vibration level requirement is also set by the decree [2] as short term weighted maximum level of 20 mm/s^2 and 300 mm/s^2 of absolute maximum on the floor. It is rare, that educational buildings would be exposed to significant ground borne disturbances.

2.1.3 Interior sound isolation

Airborne sound isolation and impact noise level requirements are set in the MSZ 15601-1 [6] standard, according to Table 1. An 'enhanced' quality is also defined with +5 dB of airborne sound isolation and -3 dB of impact noise levels. This was requested by a client only once in the author's praxis. The standard allows to add corrections if the building is 'multifunctional'. For example, correction is +10 dB of airborne sound isolation and -10 dB of impact noise level if the noisy room is used as a music education room or gymnasium. This 'multifunctional' naming is confusing and therefore often neglected by colleagues.

Table 1. Sound isolation requirements for educational buildings, according to the MSZ 15601-1:2007 [6] standard (values are in dB).

situation			measure		airborne sound isolation			impact
room to protect	adjacent	noisy room, exposed structure			total	wall	door	
class room, lecture room, kindergarten or nursery room, office, teachers' room	horizontal	class room, lecture room, kindergarten playroom, office, teachers' room	R'_w+C	in situ	45	-	-	-
		washroom, toilet, kitchen	R'_w+C	in situ	45	-	-	-
		circulation, corridor, staircase	R_w+C	lab	-	45	27	-
		circulation, corridor, staircase floor	L'_{nw}	in situ	-	-	-	55
		attic, basement, storage	R_w+C	lab	-	45	-	-
	vertical	class room, lecture room, kindergarten playroom, office, teachers' room, washroom, toilet, kitchen	R'_w+C	in situ	51	-	-	-
			L'_{nw}	in situ	-	-	-	55
		circulation, corridor, staircase	L'_{nw}	in situ	-	-	-	55
		attic, basement, storage	R_w+C	lab	51	-	-	-
			L'_{nw}	in situ	-	-	-	55

The concept and the range of values are reasonable, but a lot of practical situations are not mentioned and the standard does not provide guidelines for dealing with unregulated situations. Also, the standard is outdated, it does not consider issues common these days (mobile partitions, open spaces, workshops etc.).

2.1.4 Sound isolation of the façade

Composite sound isolation of the façade must be calculated according to the MSZ 15601-2 [3] standard using equation

$$R_w + C_{tr} \geq L_{1AM} - L_{2A} + 10 \cdot lg\left(\frac{S_h}{A}\right) + K_h + 2\text{dB} \quad (1)$$

where L_{1AM} is the noise load averaged over the façade, S_h is the surface of the façade. K_h can be 0 dB, 3 dB or 6 dB depending on the positions to measure L_{1AM} and if the façade is reflecting. The last term is added due to the assumed minimum deviance of in situ and in-laboratory performance of the structure.
The standard accepts to use correction factor C if the noise load spectrum allows.

2.1.5 Room acoustics

There were no regulations or national standards on room acoustic requirements until the MSZ 2080:2020 [1] standard was published. Development of this standard took more than four years of negotiations, starting from latest versions of other national standards in Europe, without considering real life conditions and without any subjective survey on how teachers or students see the situation.
Table 2 shows room acoustic requirements of the MSZ 2080 [1] standard for room types relevant to educational facilities. Maximum mean reverberation time is calculated or measured in unoccupied rooms. Minimum mean absorption is total absorption built in the room, calculated from material data. Mean is calculated from 250 Hz…2 kHz octave data.
Last rows are volume-dependent requirements for rooms, where volume-independent requirements could not be recognized. A room with volume-dependent reverberation time requirement must also comply to a frequency-tolerance (see Fig. 1).
As one can see, this standard is rather complex, somewhat contradictory and in many cases unpractical (too strict or might not cover practical situations).
An informative appendix of the standard suggests speech transmission index requirements of STI ≥ 0.60 for classrooms or lecture halls (except for musical purposes) and STI ≥ 0.75 for language labs. Here requirements are simple spatial averages calculated or measured at listening positions. Another informative appendix suggests maximum length/width sizes of classrooms based on the constraint (see Fig. 2) that early reflections (within 35 ms or 50 ms

respectively) from walls should support speech. The aim is to support smaller rooms or groups if speech is important.

Table 2. Room acoustic requirements for educational facilities taken from the MSZ 2080:2020 [1]. (For explanations, see 2.1.5).

function of the room	range of volume	range of height	max. of T_{m4}	min of A_{m4}/V
	m^3	m	s	m^2/m^3
language lab	≤ 250	-	0.5	-
teleconferencing room	-	-	0.5	-
kindergarten or nursery room	≤ 250	-	0.6	-
classroom, lecture rooms in educational facilities (except for music rooms)	≤ 250	-	0.7	-
reading room of libraries	≤ 250	-	0.7	-
	> 250	≤ 3.2	-	0.20
		> 3.2	-	0.15
meeting room	≤ 250		0.7	-
office (more than 2 person)	-	≤ 3.2	0.8	-
	-	> 3.2	-	0.15
office (1-2 persons)	-	≤ 3.2	1.0	-
	-	> 3.2	-	0.15
restaurant or canteen of educational facilities	-	-	1.2	-
sports halls and gyms	≤ 500	-	1.2	-
lobby of educational facilities	≤ 1500	-	1.5	-
	1500…5000	-	2.0	-
workshops in educational facilities	≤ 500	≤ 3.2	-	0.20
	≤ 500	> 3.2	-	0.15
circulation and corridor of educational facilities (except	-	≤ 3.2	-	0.20
	-	> 3.2	-	0.15
speech	250…3,000	-	0.44·lg(V)-0.36	-
amplified music	250…3,000	-	0.75·lg(V)-1.10	-
unamplified music	30…3,000	-	0.84·lg(V)-0.77	-
sports	500…10,000	-	0.90·lg(V)-1.20	-
	10,000…30,000	-	2.4	-

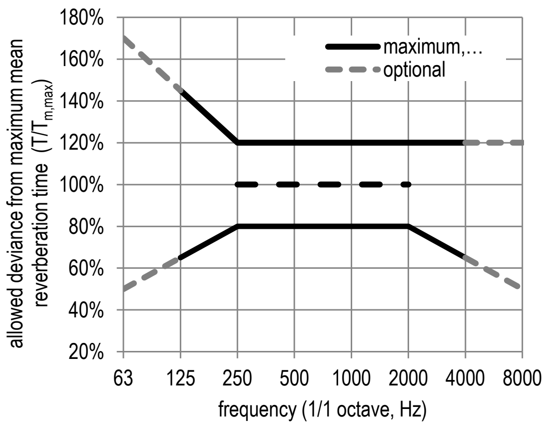

Figure 1. Frequency dependent tolerance of reverberation times according to [1].

2.1.6 Non-acoustic requirements

General infrastructural requirements of educational facilities are set in decree 253/1997 [7] and the standard series MSZ 24203 [8]. These include minimum floor dimensions for each typical rooms and a minimum free height of 3 m for classrooms, for example. It is worth to note, that the decree 253/1997 [7] recognizes noise and vibration protection as essential building characteristics among the acoustic characteristics, but room acoustics is not mentioned. None of these documents set acoustic requirements but refer to relevant standards as acceptable qualities.

2.1 Typical project cycles

Typical design stages and roles are shown in Figure 1. Not all stages appear in projects, but permit and construction stages are clearly defined. Design and engineering teams are led and coordinated by architects exclusively. Bidding is sometimes based on permit documents with loose specifications, which makes quality control difficult.

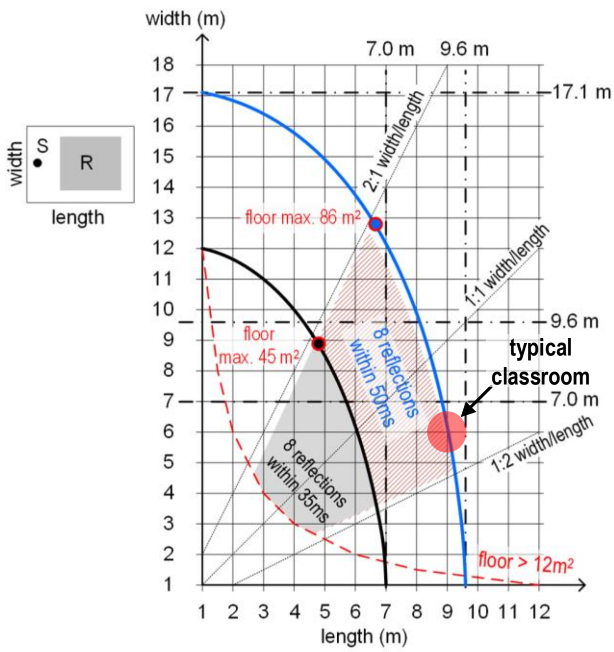

Figure 2. Classroom sizing chart from [1], based on minimum required number of early lateral reflections. (source S is in front center, receivers R within 1m of walls).

Acoustically competent representatives are rarely found on behalf of the client, leaving no resources to support engineering control and evaluation during or after

construction. Communication and understanding of acoustic requirements are often far from fluent and overall tolerance against acoustic problems is rather high. Real acoustic problems are rarely spotted, evaluated, corrected.
In the praxis of the author, acoustic measurements are usually initiated by the acoustician for own interest with no mandate, just to collect data and experience, years after completion.

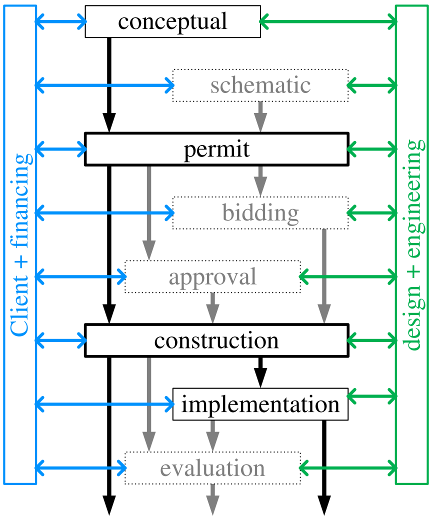

Figure 3. Scheme of typical design stages and roles. Timeline is from top to bottom.

3. SURVEY

Starting during the discussions of the [1] standard, the author took measurements to collect data and also asked teachers about their acoustic experiences during their work.
This survey, however, this survey focuses on room acoustic attributes of unoccupied rooms. Discussion of other attributes are based on less data and experience collected from ad hoc small group conversations and questionnaires.

3.1 Room acoustic measurement results

Measurement results were collected mostly by the author, using omnidirectional or in some cases slightly directional sources (small-sized 2-way active speaker with a 4” woofer). In some cases, only reverberation time data is available from sound isolation control measurements. Other than that, measured impulse responses were recorded and evaluated according to the ISO 3382-1 [9] and the ISO 18233 [10] standards. Speech transmission index (although not a room acoustic parameter) is evaluated using the EN 60268-16 standard with the indirect method, without masking.

3.1.1 Reverberation and decay times

A scatter plot of measured mean reverberation times are shown in Figures 4 and 5.
Figure 4 differentiates categories based on the function of the room and the condition of the acoustic treatment. Here ‘aged’ treatment means, that visually the surface treatment is acoustically significant, but there is no information on the design. Rooms where no obviously (visually) sound absorbing surfaces could be identified are denoted as ‘no’ treatment.

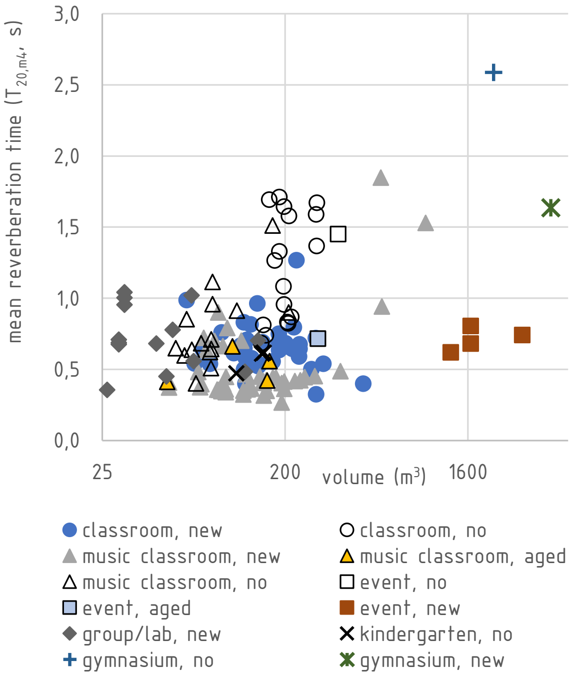

Figure 4. Measured mean reverberation times of rooms in educational facilities as a function of volume, grouped by the condition of room acoustic treatment.

Figure 5 differentiates the same measurement results upon condition within the room. Empty rooms have no furniture. In ‘hardly furnished’ rooms single objects were sparse or were stacked along walls. An ‘inhabited’ room contains other objects (personal belongings, decorations, books etc.) in addition to furniture (chairs, tables and shelves).
Figure 6 shows the relationships of T_{m2} (mean of 500 Hz, 1 kHz bands), T_{m3} (mean of 500 Hz, 1 kHz, 2 kHz bands) and T_{m4} (mean of 250 Hz, 500 Hz, 1 kHz, 2 kHz bands).
Frequency balance of reverberation times was checked against a simplified tolerance fit, used by the author, shown in Fig. 7. Here the mean (or central) reverberation time is

$$T_{m0} = \frac{max\{T_{250\text{Hz}...8\text{kHz}}\} + min\{T_{63\text{Hz}...2\text{kHz}}\}}{2} \quad (2)$$

After fitting the tolerance, parameters a/T_{m0}, b and c can be interpreted as relative midband ripple, bass ratio and high frequency roll-off respectively. Results are shown in Fig. 8. Figure 9 shows $EDT_{10,m4}$ mean early decay times against T_{m4} mean reverberation times.

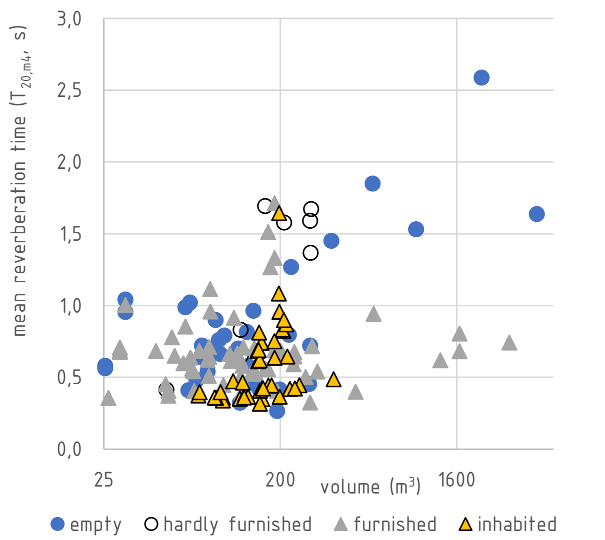

Figure 5. Measured mean reverberation times of rooms in educational facilities as a function of volume, grouped by the condition of the room.

3.1.2 Clarity and intelligibility

To describe speech intelligibility of a response, speech transmission index (STI) is usually suggested. Figure 10, 11, 12 and 13 show correlation of STI against mean reverberation time, mean early-decay time and mean early-late ratios of C_{50} and C_{80} respectively.
In Figure 10, a 'worst-case estimate' is also shown based on equation

$$STI \geq 0.2 \cdot ln(T_{20,m4}/T_0) + 0.55 \quad (3)$$

where $T_0 = 1\text{s}$. This equation is an empirical estimate of the minimum expected STI, based on a large number of measurement results. Obviously, this estimate does not consider effects of vocal effort, spectral masking, background noise masking etc. that a proper intelligibility assessment would require. It supports however that effects of room acoustic response by itself on speech intelligibility is fundamentally governed (not defined!) by the reverberation time.

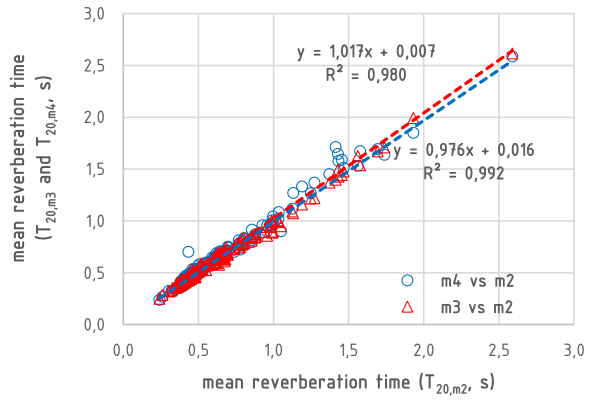

Figure 6. Comparison of different measured mean reverberation times.

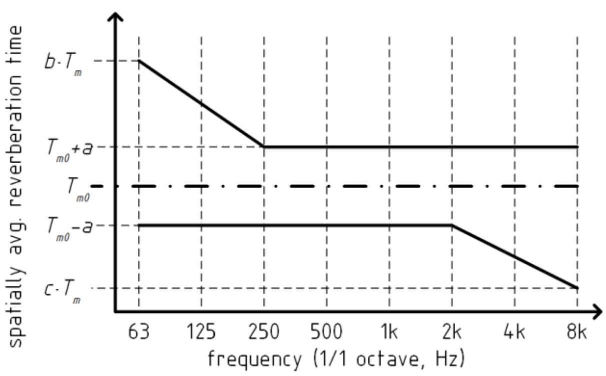

Figure 7. Reverberation time tolerance to fit.

3.1.3 Strength

Strength was derived using measured dimensions L, W, H and reverberation time (see [13])

$$G = 10 \cdot log_{10}\left[\frac{1}{r^2} + \frac{16 \cdot \pi}{Q \cdot S \cdot \alpha^*} \cdot (1 - \alpha^*)^{r/l+1}\right] + 20.1\text{dB} \quad (4)$$

where $r = \sqrt{L \cdot W}/2$ is a representative distance, $Q = 1$ assumed for the source, $l = 4V/S$ is the mean path length, α^* is the total attenuation including mean air absorption and S is the surface area of the boundary. Total absorption is calculated from equation $\alpha^* = 6 \cdot ln(10) \cdot l/(c \cdot T)$ where T is the statistical reverberation time, which is assumed to be equal to $T_{20,m4}$.

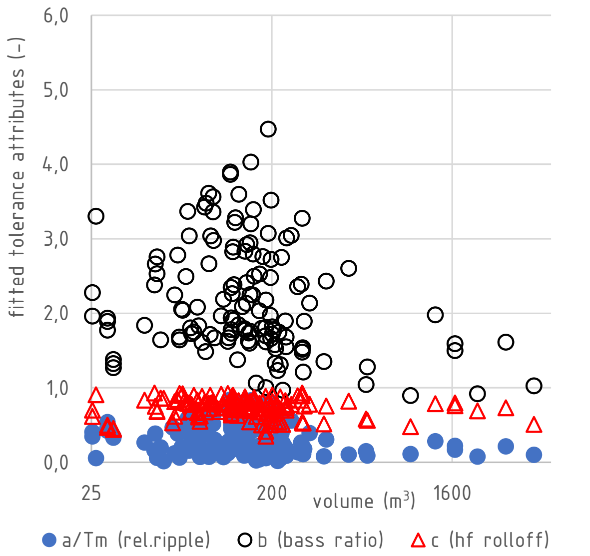

Figure 8. Parameters of frequency dependent tolerance (see Fig. 7) of measured reverberation times.

Correlation of STI to early-decay time and clarity measures is better, as they are more related to direct-to-reverberant ratio.

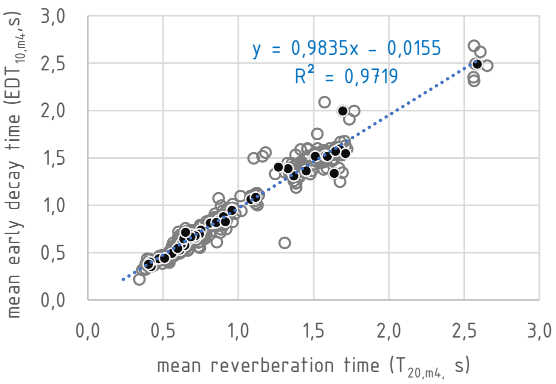

Figure 9. Mean early-decay times against mean reverberation times. Filled circles mean average values for each room, hollow circles show each measurement.

3.1 Observations from questionnaires and interviews

Both interviews and questionnaires showed that teachers are completely unaware of room acoustic effects on their work or on the behavior of children. Complaints were mainly about occasional noise intrusion from the street or weak sound isolation of the doors.

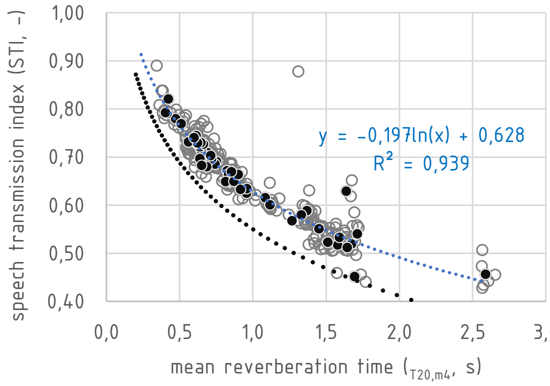

Figure 10. STI correlation to mean reverberation time $T_{20,m4}$ (○ each measurement, ● each room).

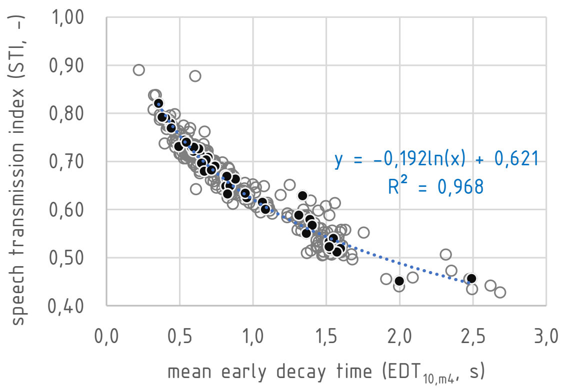

Figure 11. STI correlation to mean early decay time $EDT_{10,m4}$ (○ each measurement, ● each room).

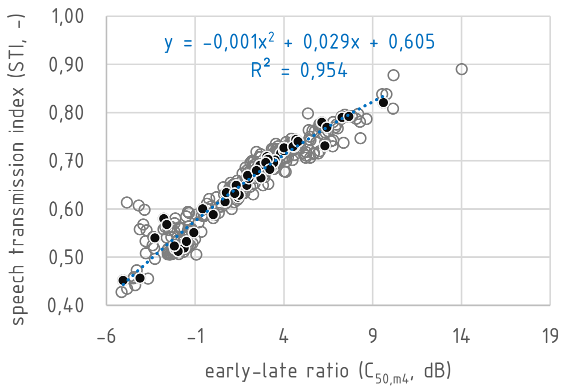

Figure 12. STI correlation to mean early-late ratio $C_{50,m4}$ (○ each measurement, ● each room).

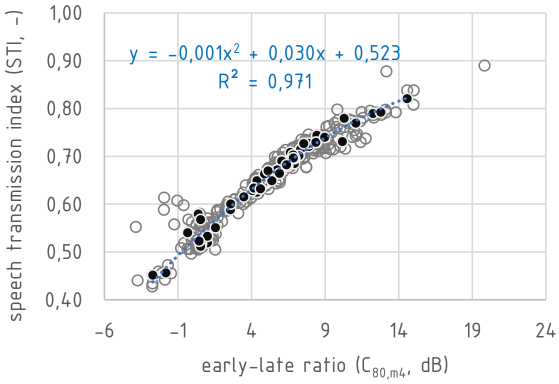

Figure 13. STI correlation to mean early-late ratio $C_{80,m4}$ (○ each measurement, ● each room).

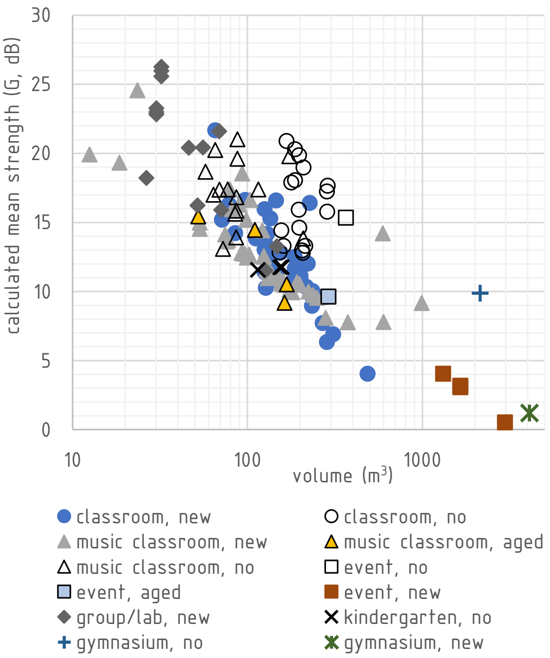

Figure 14. Calculated mean strength (see Eq. 3).

After listening to what teachers had to say, the author explained them about main room acoustic phenomena. Usually, teachers were surprised and understood that among others, overall noise level, intelligibility, quality of focus and student behavior are all affected by room acoustics. This revelation was more obvious for teachers working in a school, where the building has both old, renovated and newly built classrooms with obviously very different acoustic qualities. They understood immediately, why it is harder to maintain discipline in certain rooms despite all their efforts.

Actual complaints related to room acoustics was only mentioned in renovated music classrooms, where musicians complained about the too dry sound, compared to what they used to hear. Other than that project, even music teachers tend to adapt and accept very bad acoustic conditions. This forgiving attitude might be due to low acoustic awareness.

4. DISCUSSION

4.1 Acoustic engineering practice in Hungary

Referring to and using currently available national standards and regulations during the design process, acoustic quality of educational facilities can be specified and designed to a satisfactory level. National regulatory documents and recommendations, however need to be updated to avoid over-complicated and ambiguous instructions of room acoustics and to clarify instructions of sound isolation for contemporary situations.

Not surprisingly, most of the rooms and event spaces of educational facilities, that were built earlier, are not acceptable by todays' standards.

Sound isolation of partitions and slabs is usually not a problem. Problems of weak sound isolation to the façade is often solved by replacing old windows.

Surprisingly even rooms without any acoustic treatment can comply current room acoustic standards, if decoration and objects stored or used in classrooms or kindergarten rooms represent significant amount of sound absorption.

After the submission of plans, acoustic engineers are usually not get involved in the bidding and construction process and control measurements are not required either. This is not a good practice that needs to be changed. Not only to ensure that acoustics will be as intended, but to get feedback to the clients and users and to collect data for further research.

It is rare to use indoor HVAC units in educational facilities in Hungary, which is usually the main cause of disturbingly high background noise levels.

In normal sized (<250 m^3) classrooms it is also rare to install a separate audio system for demonstration purposes and built-in loudspeakers of devices (e.g. smartboards) or separate small loudspeakers suffice.

4.2 Lessons learned from measurements and experience

Reverberation time alone might seem to be old-fashioned to use as the most important parameter, but according to statistical models, geometric modelling and measurements, reverberation time is indeed a "worst-case" indicator and a good way to avoid fundamental mistakes.

There are no significant benefits of using m3 or m4 over m2 mean values of reverberation times in specifications, only that m4 is more relatable to NRC values commonly used on datasheets of architectural materials.
Using STI to specify room acoustic response is unnecessary, while noise limits should be given explicitly, not implicitly. A mean reverberation time lower than 0.8 s can safely ensure that room response will not degrade STI below 0.60.
Both occupancy and objects in addition to basic furniture will shorten reverberation times, while a too short reverberation time can also be problematic (see [14]). Classrooms for 7-10 years old children should support both speech and singing.
Except for strictly frontal lecture rooms, there should be no designated speaker positions or directions considered during the design, because clarity is important to everyone.
Targeting an equal frequency balance of reverberation times at low frequencies is not necessarily preferred, due to non-linear hearing (see Phon vs. SPL). A pronounced bass support is welcome by both teachers and students at normal speech levels, even in case of music classrooms and practice rooms for individuals or groups.
Most specifications rely on cubic volume and reverberation time, but causation of physical attributes suggest (see [13]), that a more meaningful set of requirements could be formulated by investigating specifications of mean path length and average architectural absorption instead.
The effect of objects on the actual mean path length should be studied in more detail, because adding non-absorbing furniture can also decrease reverberation by shortening characteristic path lengths. As a result of this, usually a single sound absorbing ceiling can be enough to achieve reverberation times T_{m4}<0.7 s and STI>0.60 speech intelligibility, in a classroom with 3 m height and <250 m^3 volume.

5. SUMMARY

Despite a far from ideal regulatory environment, the acoustic quality of new educational facilities in Hungary is good. The challenge ahead is to rationalize design aspects, to simplify the regulatory environment and to support teacher awareness and acoustic renovation of old existing classrooms.
The author would like to thank A. B. Nagy to allow reusing measurement data of two facilities he provided earlier [12].

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