Environmental noise perception by students and teachers and simulation of the Speech Transmission Index

Carmen Lucia Pezzette Loro
Master's Degree in Civil Engineering, UFPR, Brazil
oro@arquiteturaloro.com.br

Eriberto Oliveira do Nascimento
Ph.D. student in Mechanical Engineering, Laboratory of Environmental and Industrial Acoustics and Acoustic Comfort, UFPR, Brazil.
eriberto.on@gmail.com

Paulo Henrique Trombetta Zannin
Full Professor Dr. -Ing. Laboratory of Environmental and Industrial Acoustics and Acoustic Comfort, UFPR, Brazil
paulo.zannin@gmail.com

ABSTRACT

As diverse as the knowledge transmission techniques aided by multimedia resources are, nothing replaces the teacher-student relationship, which is developed in the classrooms. Therefore, classrooms must offer the necessary conditions for the satisfactory development of teaching and learning activities. In this context, the importance of classroom acoustics is highlighted. The Speech Transmission Index (STI) is one of the broadest and most important parameters to measure speech intelligibility. STI weighs the effects that can cause deterioration on the voice signal, such as the reverberation time and background noise. This work presents an evaluation of the acoustic performance of classrooms using the STI. For that, three constructive patterns were evaluated. The constructive models were named 010, 022 and 023. Students and teachers answered a questionnaire about the perception of noise in the classroom and at school, and the constructive pattern 023 was studied. Computer simulations were performed with ODEON software to precited STI. The results of the measurements and the questionnaires revealed that the noise that disturbs the activities in the classroom comes from the school itself, not only from the other classrooms, corridors and adjacent patios, but also from inside the classroom itself.

KEYWORDS: Speech Transmission Index. Room acoustics. Reverberation Time. Acoustic quality

1 INTRODUCTION

Education is as essential in societies today as it was in the past. Most formal instruction takes in classrooms, where learning includes verbal communication between instructors and pupils. As diverse as the knowledge transmission techniques aided by multimedia resources are, which are increasingly common, nothing replaces the teacher-student relationship, which is developed in the classroom. Therefore, classrooms must provide the necessary conditions for the satisfactory development of teaching and learning activities, especially the teacher-student communication. In this context, the importance of classroom acoustics is highlighted (ZANNIN et al., 2009; NASCIMENTO, E. O. et al., 2018).

The Speech Transmission Index (STI) is one of the broadest and most important parameters of speech intelligibility. The speech transmission index considers most of the conditions that can cause deterioration of speech intelligibility, such as reverberation time and the background noise (PENG; LAU; ZHAO, 2020).

This work presents an evaluation of the acoustic performance of classrooms in reference to the acoustic descriptor STI. For that, three constructive patterns were evaluated. The constructive models are named 010, 022 and 023. Students and teachers answered a questionnaire about the perception of noise in the classroom and at school, being studied the constructive pattern 023, which is the most common among the three mentioned patterns above. To assess the acoustic quality of the classrooms, computer simulations were performed with the ODEON software to predict the Speech Transmission Index.

2 METHODOLOGY

2.1 Description of the Constructive Standards for Classrooms in the State of Paraná

The classrooms of the evaluated public schools are designed in standard modules that can be adjusted to the needs of new schools, depending on the expected number of students and the type of land where they will be built. Table 1 presents the description of the evaluated classrooms.

Table 1: Description of the evaluated classrooms

Classroom	Volume	Wall material	Floor material	Ceiling material	Window type
010	139 m³	Ordinary brickwork	Parquet	Wood paneled ceiling	Iron window frames with glass panes
022	139 m³	Ordinary brickwork	Parquet	Concrete slab	Iron window frames with glass panes
023	156 m³	Ordinary brickwork	Ceramic tiles	Concrete slab	Iron window frames with glass panes

Source: The Authors, 2021

The characteristics of the selected construction projects were as follows.

1) Project, which comprises of autonomous squares with a central circulation range and classrooms organized on both sides of a passage;

2) Project 022, composed of classroom blocks arranged side by side without a corridor between them;

3) Project 023, like project 010, composed of independent blocks of classrooms arranged on both sides of a central corridor.

2.2 Teachers' and students' perception of noise in the classroom

To assess the perception of teachers and students about noise in classrooms, a questionnaire was designed for each class. The interviews involved (n = 15) teachers and (n = 185) of the 6th and 8th grade. The aim of the questionnaire was to investigate the sources of noise in classrooms and the degree of disturbance it caused to teachers and students.

The questionnaire included a scale to be assigned to each answer: (0) No Interruption, (1) Very Small Interruption, (2) Small Interruption, (3) Moderate Interruption, (4) Considerable Interruption, (5) Intense disturbance, (6) Extreme disturbance from noise. Descriptive statistical analysis was used to assess the results of the questionnaires.

2.3 Speech Transmission Index Assessment

The Speech Transition Index is an acoustic descriptor that considers the effects of reverberation, background noise and the contribution of the acoustic source directivity to determine speech intelligibility, as shown in Eq. 1. These elements, which are usually treated individually, are combined into a single index (MAPP, 2020).

$$m(f_m) \cong \left\{ 1 + \left(2\pi \frac{T}{13.8} \right)^2 \right\}^{-1} \left[1 + 10^{-SNR/10} \right]^{-1} \tag{1}$$

and

$$SNR_k = L_{op,k} - L_{BGN,k} \tag{2}$$

where, $m(f_m)$ is the modulation reduction factors, T is the reverberation time for each octave band, SNR is the signal-to-noise ratio, $L_{op,k}$ is the sound pressure level spectrum of normal speech, also known as operational speech level, and $L_{BGN,k}$ is the background noise level for

the k octave band. After calculating the modulation factors, the STI is calculated according to IEC 60268-16 procedures (IEC, 2011). Finally, $L_{op,k}$ is obtained according to the ANSI standard (ANSI, 2010), as shown in Table 2.

Table 2: Operating speech level at the receiver from one meter of source.

Normative	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
ANSI/ASA S12.60	#	57.2	59.8	53.5	48.8	43.8	38.6
IEC 60268-16	2.9	2.9	-0.8	-6.8	-12.8	-18.8	-18.8

Source: The Authors, 2021

STI was simulated with Odeon 9.0 software using the hybrid method. Rindel (2000) states that the hybrid methods combine the best characteristics of the image source and ray tracing methods. A comparison of various computer simulation methods indicated that programs using the hybrid method produce the best results.

The STI simulations were performed in accordance with the IEC 60268-1617 standard (IEC, 2011). To obtain acoustic parameters through simulations, it was first necessary to conduct a three-dimensional modeling of the classroom. Appropriate calculation parameters were entered (such as impulse response length), surface finish characteristics (absorption and scattering coefficients) and sound source and receiver specifications. For the mouth simulator source, the IEC 60268-16 standard establishes that it must function as proxy to the human voice spectrum, i.e., emulate a human voice sound field. The noise generated by the source should simulate the timbre and volume of the human voice.

The three-dimensional models were calibrated based on the comparison of measured and simulated RT values. The RT measured was obtained according to the ISO 3382-2 standard (ISO, 2008). The values of an octave band frequency sound pressure level measured in the classroom were entered into the calibrated model and the speaker and microphone positions defined. A 0.50 x 0.50 m grid was defined for the speakers, and the microphone was placed in the typical teacher's position and directed towards the students.

3 RESULTS

3.1 Subjective assessment of noise perception

Teachers were asked to identify the noise sources that most disrupt classroom activities. They cited noise from neighboring classrooms at level 2.68 (between an exceedingly small disturbance and a small disturbance) as the main source of disturbance. Noise generated in their own classroom and noise generated by teachers' voices in neighboring classrooms received scores of levels 2 (little interruption) and level of interruption 1.6 (between ridiculously small disturbance and small interruption).

On the other hand, half of the students, i.e., 49%, consider their classroom to be noisy, and the other half, 49%, consider their classroom to be normal. Only 2% of students interviewed considered their classroom to be silent. In addition to the students' perception of noise in the environment, it can impair their learning performance. In the school environment, 95% of the interviewed students believe that noise in the school environment can affect their learning performance. The students mentioned as the main sources of disturbance in the

classroom: 1) noise inside the classroom itself, 2) noise caused by students in other classrooms and 3) the teacher's voice in the next classroom. These three sources together represent 98% of the disturbance perceived by students.

Teachers indicated that the activities in the classroom most strongly affected by noise are lectures, comprehension, individual reading and taking tests. Teachers attributed the same score - level 4 (considerable disturbance) and level 5 (intense disturbance) - for all these activities, demonstrating that they are strongly affected by noise. In the same way that teachers indicated that students perceive that taking tests, individual reading and lectures given by the teacher are activities strongly affected by noise.

According to the teachers, the noise generated outside the classroom, but inside the school building, is caused by people talking in the hallway. Students answered the same question: "With what factor/sound source is noise generated outside the classroom, but inside the school building related? "The results indicated that 51% of students cited conversations in other classrooms as the main source of disturbance within the school building. In addition, 48% of students stated that people talking and walking in the corridor is the second largest source of disturbance within the school building.

3.2 Acoustic quality

Table 3 presents, in octave band frequency, the absorption sound coefficient of the classroom ceiling finishing material used in the simulations. In the 023-construction model, there is no ceiling finishing material, consisting simply of concrete slabs, so an acoustic fiberglass lining plate was used in the simulations.
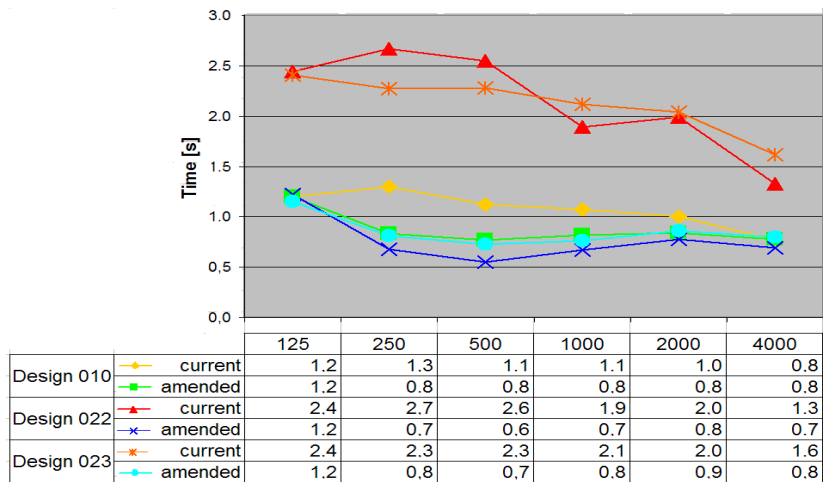
Table 3: Sound absorption coefficient of the ceiling used in the acoustic simulations.

Material	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
Fiber glass	0.33	0.33	0.79	0.99	0.91	0.76	0.64	0.64

Source: The Authors, 2021

Figure 1 shows the simulated RT with the existing ceilings in classrooms and with the acoustic fiberglass ceiling. As can be seen in Figure 1, there is a significant decrease in RT values, especially in the classrooms of the 022 and 023 design standards, which do not have a type of ceiling finish.

Figure 1: Reverberation time before and after the acoustic ceiling placement

			125	250	500	1000	2000	4000
Design 010	current		1.2	1.3	1.1	1.1	1.0	0.8
	amended		1.2	0.8	0.8	0.8	0.8	0.8
Design 022	current		2.4	2.7	2.6	1.9	2.0	1.3
	amended		1.2	0.7	0.6	0.7	0.8	0.7
Design 023	current		2.4	2.3	2.3	2.1	2.0	1.6
	amended		1.2	0.8	0.7	0.8	0.9	0.8

Source: The Authors, 2021

In addition to RT, STI was simulated with corrected ceiling finish. For background noise, two sound pressure levels of 34 and 60 dB(A) were used, they measured in the classroom. Figure 2 shows the example of the measured background noise.

Figure 2: Measured background noise spectrum
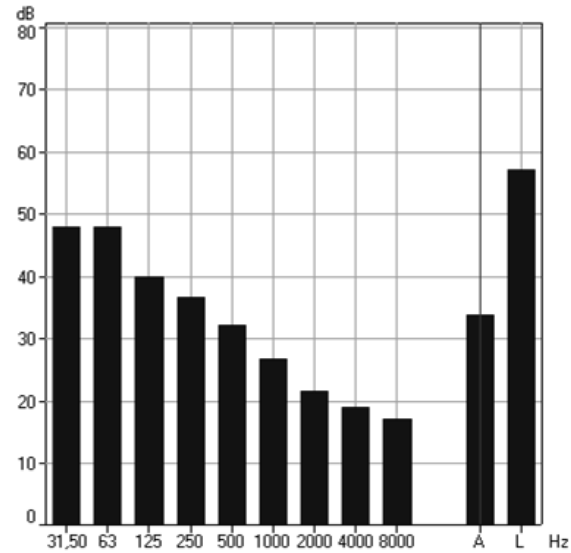
Source: The Authors, 2021

Figure 3 shows the STI maps of design patterns 010, 022 and 023, for two background noise levels 34 and 60 dB(A) and two RT situations, i.e., the current situation and situation with changed ceiling material with the data from Table 3.

Figure 3: Relation of Reverberation Time, Background Noise and Speech Transmission Index
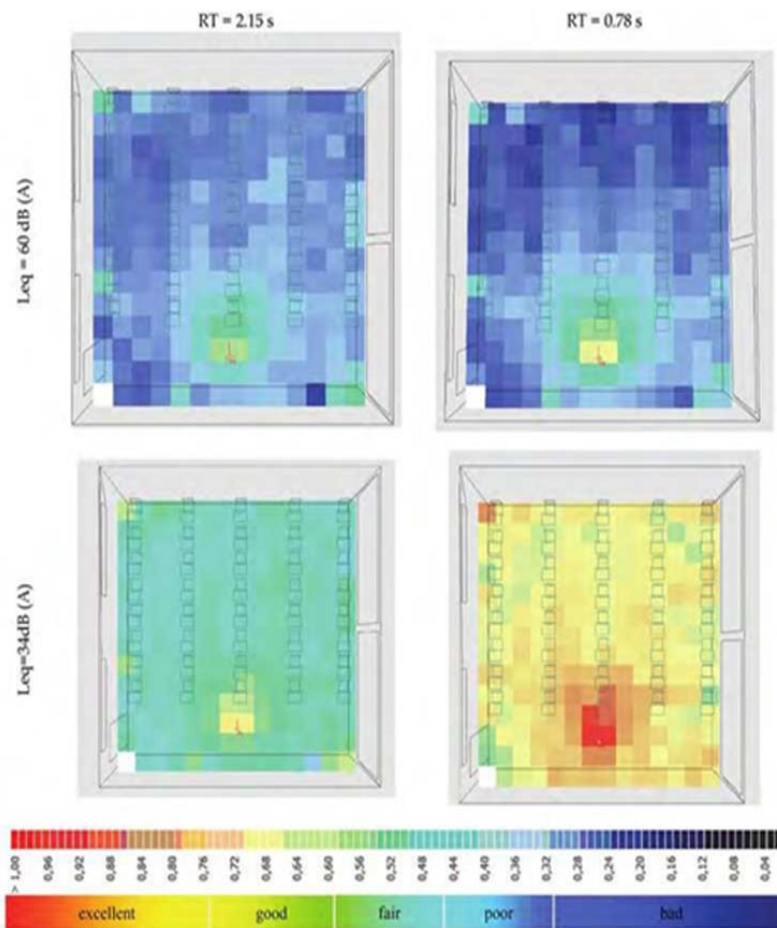
Source: The Authors, 2021

In Figure 3, the map in the first column and first row of the figures represents the current situation of the classrooms in terms of Reverberation Time (RT) and Sound Pressure Level (NPS). The maps in the second column and first row represent the simulation with RT reduction by replacing the current ceiling finishing material with a material with greater sound absorption coefficient and maintaining the background noise at 60 dB (A).

Comparison of these maps with the current situation indicates that the STI worsened at the points furthest away from the sound source, classifying them as "poor" to "poor" intelligibility. The maps in the second row and first column represent the STI for the current RT situation in classrooms, with reduced background noise. These maps show a significant improvement in speech intelligibility, especially in the standard project classroom 010, whose RT was lower than in the other classrooms. For this room, the map in this situation generated an ITS from "good" to "excellent". For design pattern classrooms 022 and 023, speech intelligibility in this RT and SPL situation is rated from "reasonable" to "good". The maps presented in the second column and second row show the STI from "good" to "excellent" for all rooms under study. This situation is characterized by low background noise and adequate reverberation time.

4 CONCLUSIONS

The results of the measurements presented here indicate that the evaluated classrooms do not offer adequate acoustic comfort for the development of educational activities. The reverberation time measured in all classrooms revealed the lack of acoustic comfort. The subjective evaluation indicated that both students and teachers perceive noise in the classroom and are bothered by it. According to teachers, noise is a factor that negatively affects teaching and learning. Most students said they listened to the teacher well. However, they considered the classrooms noisy and stated that the listening activity was the most impaired. This statement was confirmed by the results of the questionnaire that the teachers answered.

The results of the measurements and the questionnaires revealed that the noise that disturbs the activities in the classroom comes from the school itself, not only from the classrooms, corridors and adjacent patios, but also, and from inside the classroom itself. Changing the ceiling finishing materials proved to be efficient, as it resulted in the RT reduction to adequate values or close to those established by construction standards. As for speech intelligibility, the STI rating from "Good" to "Excellent" was only achieved through a combination of reduced background noise and reduced RT within classrooms.

BIBLIOGRAPHICAL REFERENCES

AMERICAN NATIONAL STANDARD INSTITUTE (ANSI). ANSI/ASA S12.60-2010/PART 1: Acoustical Performance criteria, Design Requirements, and guidelines for Schools, Part 1: Permanent Schools. Acoustic Society of America, 2010.

INTERNATIONAL ELECTROTECHNICAL COMMISSION (IEC). IEC 60268-16: Sound system equipment – Part 16: Objective rating of speech intelligibility by speech transmission index. Switzerland, 2011.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO). **ISO 3382-2**: Acoustics -- Measurement of room acoustic parameters -- Part 2: Reverberation time in ordinary rooms, Switzerland, 2008.

MAPP, P. Speech Transmission Index (STI): Measurement and Prediction Uncertainty. **Uncertainty in Acoustics: Measurement, Prediction and Assessment**, p. 217, 2020.

NASCIMENTO, E. O. et al. Mobile Learning and Computational Simulation Applied in Environmental Acoustics. **IEEE Latin America Transaction**s, v. 16, n. 1, p. 265-271, 2018.

PENG, J.; LAU, S-K; ZHAO, Y. Comparative study of acoustical indices and speech perception of students in two primary school classrooms with an acoustical treatment. **Applied Acoustics**, v. 164, p. 107297, 2020.

RINDEL, J. H. The use of computer modeling in room acoustics. **Journal of vibroengineering**, v. 3, n. 4, p. 219-224, 2000.

ZANNIN, P. H. T.; ZWIRTES, D. P. Z. Evaluation of the acoustic performance of classrooms in public schools. Applied Acoustics, v. 70, n. 4, p. 626-635, 2009.