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Technical note

Fast estimation of Speech Transmission Index using the Reverberation Time: Comparison between predictive equations for educational rooms of different sizes

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ABSTRACT

Ensuring a high speech intelligibility is an essential issue for educational rooms, especially in relation to the effectiveness of the student learning process. The Reverberation Time and the Speech Transmission Index are objective parameters commonly used to assess the acoustic quality of the rooms, according to their intended use. Especially the Speech Transmission Index can give interesting information about the speech intelligibility. As with the Reverberation Time, it would be very important to have simple equations aimed to the prediction of Speech Transmission Index values during the early design stage. There are different studies in the literature that propose equations, obtained on empirical basis, for a fast estimation of the Speech Transmission Index as a function of the Reverberation Time. In this paper, a comparison of the most significant equations proposed in the literature was done using the Reverberation Time and Speech Transmission Index values obtained from a measurement campaign at the School of Engineering of the University of Pisa on a sample of 11 educational rooms. The analysis was carried out for educational rooms of different sizes, in order to highlight differences in the prediction accuracy depending on the volume of the rooms. From the analysis results it was possible to highlight the equation that shows the best accuracy in predicting the experimental data for the sample of investigated rooms and propose, through a regression analysis, two new equations for the rapid estimation of the Speech Transmission Index.

1. Introduction

The good acoustic quality is an essential requirement for classrooms in which the education of new generations takes place by a learning process involving intensive verbal communication between teachers and students [1–4]. Poor acoustic performance of the classroom can affect both the understanding of the students and the physical stress of the teachers [3–6]. Reverberation Time (RT) and Speech Transmission Index (STI), among others, are two major parameters which are commonly used to assess the acoustic properties of the classrooms with regard to verbal communication [4,7]. In particular the use of the STI is suitable for all cases in which the assumption to evaluate the intelligibility of speech by only one index (obtained by the weighted contributions of individual frequency bands) is adequate [14]. The STI is a common objective parameter used to assess speech intelligibility [8–10] not only in classrooms but also in conference halls, theatres, public address [11–13]. While the RT can be reasonably estimated with simple equations, even during the early design stage of a building, the STI generally requires more complex evaluations or in situ measurements which are difficult or impossible to achieve during the early design stage [15–18].

In accordance with the aforementioned baseline materials, it is likely to understand the usefulness of, especially for educational rooms, simplified equations aimed to the prediction of STI values, in the early design stage. There are several studies in the literature that propose equations, obtained on empirical basis (using the results of in situ measurement campaigns), with which it is possible to make a fast estimation of the STI as a function of the RT values [19–22]. Among these, four different equations were selected and considered in the present study, for both the methodological rigor and the completeness of the data by which they were obtained.

In 2004, Tang and Yeung [20] presented the results of RT, STI and the Rapid Speech Transmission Index (RASTI) measurements on a sample of 18 classrooms, where at least six measurements at different locations were performed in each classroom. By using the measurement results, Tang and Yeung proposed a regression analysis involving 100 different simple curve forms to correlate RT and STI. From this analysis, they pointed out that a logarithmic regression equation best fits the

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measured data. Considering the RT at the frequency of 500 Hz (RT_{500}), the regression equation found in [20] is:

$$STI = 0.5895 - 0.4422 \log_{10}(RT_{500}) \quad (1)$$

The regression equation fitted the measured data with a determination coefficient (R^2) equal to 0.830 and a standard error equal to 0.03. Since the STI depends on the information in several octave bands, Tang and Yeung also derived different regression equations, with the same curve form of Eq. (1), by considering broadband reverberation times (i.e., from 250 to 4000 Hz, from 500 to 4000 Hz, and from 500 to 1000 Hz).

In 2015, Gomez Escobar and Barrigon Morillas [21] showed the results of acoustic measurements on a sample of 17 classrooms. The RT, the background noise, the STI, and the Definition index (D_{50}) were measured for each classroom. Based on the regression analysis of the measurement results, Gomez Escobar and Barrigon Morillas proposed a linear and a logarithmic regression equations to correlate RT and STI. Considering the RT at the frequency of 500 Hz, the regression equations found in [21] are:

$$STI = 0.778 - 0.143\, RT_{500} \quad (2)$$

$$STI = 0.634 - 0.192\ln(RT_{500}) \quad (3)$$

The regression equations fitted the measured data with $R^2 = 0.923$, and $R^2 = 0.971$, respectively. Also Gomez Escobar and Barrigon Morillas derived different regression equations, with the same curve forms of Eqs. (2) and (3) by considering broadband reverberation times (i.e. from 500 to 1000 Hz, from 500 to 2000 Hz, and from 125 to 4000 Hz).

In 2016, Nowoswiat and Olechwska [22] discussed an experimental and theoretical analysis, on a sample of six classrooms with different shape and volume, in an attempt to the quick determination of the STI knowing only the Reverberation Time of the room. With the results of their analysis, the STI was described using a logarithmic function whereof argument was the room Reverberation Time. Considering the RT at the frequency of 500 Hz, the regression equation proposed in [22] is:

$$STI = 0.6488 - 0.2078\ln(RT_{500}) \quad (4)$$

The regression equation fitted the measured data with $R^2 = 0.989$.

Although these regression equations are accurate with respect to the data measured by the respective research groups, a comparison of their accuracy in predicting the values of STI on a same sample of educational rooms is not currently present in the literature. In this paper, a comparison of the regression equations proposed in [20–22] was done using the measurement results of the RT and STI values obtained with a measurement campaign field measurement at the School of Engineering of the University of Pisa on a sample of 11 educational rooms. From the activity carried out it was possible to determine the prediction accuracy for each of the considered equations and to highlight the equation that showed the highest accuracy. The analysis was carried out for educational rooms of different sizes in order to highlight if there was a difference in the prediction accuracy depending on the volume of the rooms. Finally, two new equations (liner and logarithmic) are proposed for the fast prediction of STI using RT by performing a regression analysis with the measured values.

2. Materials and methods

2.1. Characterization of the analysed educational rooms

In the present paper, 11 educational rooms (named C1, C2, …, C11) of the School of Engineering of the University of Pisa were analysed. The rooms were selected based on their dimensions, in order to evaluate different net floor areas (A) and net volumes (V). The rooms in the sample have volumes between 168 m^3 (C1 room, see Table 1) and 1200 m^3 (C11 room, see Table 1) and capacities between 40 and 216 seats (excluding teacher stations).

Similarly to previous studies [18], the rooms were divided into three groups: small (S) with volumes lower than 350 m^3, medium (M) with volumes in the range of 350–650 m^3, and large (L) with volumes higher than 650 m^3. All the rooms have rectangular shapes, but they are characterized by different use and different floor types: in the sample, each room is indicated as teaching (TR) or drawing (DR) room with flat or stepped floor. The main geometrical properties of the rooms in the sample, with the indication of the use and type of floor, are shown in Table 1. As it can be observed from Table 1, the drawing rooms have ratios among seats and volume much lower than the teaching rooms. Furthermore, different materials that make-up the internal envelopes of the investigated rooms and the percentages of S_{aF} occupied by the different materials are shown in Table 2. Based on their placements, the materials are grouped into four areas: floor, ceiling, walls and rest (the rest area is composed for the most part of fixed furniture). The average values of sound absorption coefficient (α_m) at the frequencies of 500 and 1000 Hz are also indicated in Table 2. The α_m values were evaluated using the values of the sound adsorption coefficient at the different frequencies, which were indicated in the datasheets of each material, provided by the Technical Office for Buildings' Management of the University of Pisa. For the materials without acoustic performance specified in the datasheets (i.e. plaster, glazed surfaces, some of fixed furniture), typical values suggested in the literature were used to evaluate α_m.

Table 1
Geometrical properties and other main characteristics of the investigated educational rooms.

ID	Size Group	No. Seats	A (m^2)	V (m^3)	S_a/V (m^{-1})	S_{aF}/V (m^{-1})	H (m)	Floor type	Use
C1	S	40	55.9	168	1.23	1.31	3.0	Horizontal	TC
C2	S	40	46.8	173	1.13	1.21	3.7	Horizontal	TC
C3	S	60	73.7	221	1.16	1.25	3.0	Horizontal	TC
C4	S	65	82.8	240	1.14	1.23	2.9	Horizontal	TC
C5	S	99	94.3	245	1.17	1.29	2.4 (2.2; 2.6)	Stepped	TC
C6	M	56	144	418	1.04	1.08	2.9	Horizontal	DR
C7	M	139	131	432	0.97	1.07	3.3	Horizontal	TC
C8	M	84	203	573	1.00	1.05	2.80	Horizontal	DR
C9	L	142	154	733	0.75	0.81	4.9 (4.2; 5.6)	Stepped	TC
C10	L	216	200	856	0.75	0.83	4.0 (2.4; 5.6)	Stepped	TC
C11	L	208	216	1200	0.64	0.69	5.7 (4.4; 7.0)	Stepped	TC

S_a = overall internal envelope surface; S_{aF} = overall internal envelope surface increased taking into account all the surfaces of the fixed furniture in the room (desks, fixed seats, cabinets…); H = height of the room (in the case of room with stepped floor, H is the average value and the minimum and maximum values are indicated in the brackets).