Classroom acoustics - Do existing reverberation time formulae provide reliable values?

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The acoustical conditions in classrooms are important in the educational task. It is well recognized that different types of absorber treatments in classrooms influence speech intelligibility. In the stage of planning such classrooms it is therefore important to predict the reverberation time sufficiently correct. The aim of this paper is to investigate the accuracy of existing reverberation time formulae and computer simulated reverberation times. Some measured reverberation times in real classrooms are also compared with predicted reverberation times. The results of this paper suggest that Eyring's formula may provide reasonable RT values if calibrated absorption coefficients obtained from measurements are applied. Using absorption coefficients from standard tables does in general yield, however, too high RT values compared to measured values.

INTRODUCTION

In classrooms usually the main absorption is on the ceiling and also on the floor due to the high audience absorption area where the pupil sits over. Using classical reverberation time formulae may therefore lead to incorrect predicted reverberation time values due to non-regular distributed sound absorption in the room. In calculating respective reverberation times (RT) it has been also well-recognised in the past that using classical RT formulae leads to differences in predicted RT values obtained using standard absorption data. Comparison of well-known classical reverberation time formulae as well as computer simulated reverberation times are presented in this paper. Measured reverberation times in eleven classrooms are reported for comparison. Also, some regulations recommend a mid reverberation time well below 1 s [1,2] in real classrooms often quite different reverberation times are perceived; especially at low frequencies.

REVERBERATION TIME FORMULAE

The reverberation time formulae that are usually given in Standards are either the Sabine or Eyring formula. Although it is well know that these reverberation time formulae are based on diffuse field theory and real rooms are likely not to fulfil these requirements, Sabine's formula is still used by acousticians. Other reverberation time formulae are that of Millington-Sette [3,4], Arau [5], Fitzroy [6], Tohyama [7], the model of Annex D of CEN prEN 12354-6 [8] and the Fitzroy-Kuttruff equation as proposed by Neubauer [9,10].

THE CLASSROOMS

Acoustical measurements of reverberation times were carried out at multiple source and receiver positions in 11 classrooms in 5 different schools. The measured RTs are shown in Figure 1. The rooms were in general rectangular having room volume of 50 m³ to 230 m³. All measurements were carried out in unoccupied rooms. Some classrooms contained absorbing ceilings some were without absorbing treatments on the ceiling. The floors were hard covered and one of the side-walls was a window-facade.

MEASEURED REVERBERATION TIMES

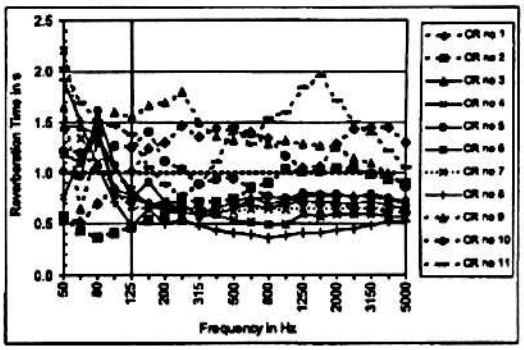

FIGURE 1. Measured reverberation time in 11 classrooms at frequencies across 50 Hz to 5 kHz.

CALCULATED RT VALUES

The calculated RT values reported are the mean values at 500 Hz and 1 kHz. The values obtained by computer simulation are performed by the CATT-Acoustic program [11], using frequency dependent diffusion factors 0.2 and 0.4 for the frequency 500 Hz and 1 kHz, respectively. The calculation results are compared with measured RT as reported in Table 1. The used absorption coefficient where taken from standard tables or from product information's and calibrated using Sabine's theory.

Table 1. Measured and calculated reverberation time at mid frequency of 500 Hz - 1 kHz using calibrated sound absorption coefficients.

No	RT [s] at Mid Frequency (500 Hz - 1 kHz) Measured and Calculated								
	M	Ey	MS	Ar	Fi	To	EN	FK	CA
1	1.3	1.2	1.2	1.5	1.8	1.7	1.7	1.2	1.3
2	0.9	0.8	0.7	1.2	1.7	1.2	1.2	0.8	0.8
3	0.7	0.6	0.5	0.9	1.6	0.8	1.3	0.6	0.8
4	0.7	0.6	0.5	0.9	1.5	0.7	1.3	0.5	0.8
5	0.7	0.6	0.5	0.9	1.6	0.7	1.4	0.5	0.8
6	0.5	0.4	0.3	0.6	1.0	0.6	0.7	0.4	0.5
7	0.6	0.6	0.4	0.8	1.5	0.6	1.3	0.5	0.8
8	0.4	0.3	0.2	0.4	0.6	0.4	0.7	0.2	0.5
9	1.3	1.2	1.2	1.5	1.8	1.7	1.8	1.2	1.3
10	0.8	0.8	0.7	1.0	1.6	0.9	1.5	0.7	0.9
11	1.5	1.5	1.4	1.7	2.0	2.1	1.9	1.4	1.5

M: Measured RT; Ey: Eyring, MS: Millington-Sette, Ar: Arau, Fi: Fitzroy, To: Tohyama, EN: Model of Annex D, FK: Fitzroy-Kuttruff, CA: CATT-Acoustic program

Table 2. Mean and standard deviation of the calculated RT at mid frequency of 500 Hz - 1 kHz using calibrated absorption coefficients. Reported is: (|Calc.-Meas.|)/Meas.*100%

	Relative Difference at Mid Frequency Mean and Standard Deviation in %							
	Ey	MS	Ar	Fi	To	EN	FK	CA
Mean	9.4	26.8	23.1	88.3	17.5	65.6	20.6	11.4
Stdv	4.0	14.5	10.9	39.6	13.5	30.4	9.9	9.7

The Eyring, Millington-Sette and the Fitzroy-Kuttruff formula provide smaller and the Fitzroy, Tohyama, Arau and prEN 12354-6 provide longer RT values than measured. The mean of the relative difference of calculated reverberation times compared to the measured RT are shown in Table 2. Indicated is the average mean and standard deviation for the mid frequency of 500 Hz and 1 kHz. The Eyring formula underestimates the RT in average less then 10% of the measured RT. The Tohyama's formula, although at mid frequencies similar to the mean of the Fitzroy-Kuttruff formula, does not seem to be consistent over the six octave band frequencies. The Fitzroy formula and the model of Annex D of prEN 12354-6 yield highest differences compared to the measured RT. It is noted that the values using the CATT-Acoustic program are systematically higher than using the Eyring formula. It has also calculated the RT using all formulae with standard absorption coefficients. The average mean of the relative difference at mid frequency of all calculations as reported in Table 3 was found to be about 40%.

Table 3. Mean and standard deviation of calculated RT at mid frequency of 500 Hz - 1 kHz using standard absorption coefficients. No calibration was applied.

	Relative Difference at Mid Frequency Mean and Standard Deviation in %								
	Sab	Ey	MS	Ar	Fi	To	EN	FK	CA
Mean	30.0	38.7	59.0	32.9	62.0	29.9	31.4	49.6	30.3
Stdv	21.7	20.7	15.9	17.7	47.0	20.3	22.8	18.9	19.7

Sab: Sabine

Using standard absorption coefficient yield in general too short RT values typically more than 35% except of Fitzroy and prEN 12354-6 which yield in most cases too high RT values. No consistency in predicting respective RT compared with measured values was observed in any RT formula as well as for computer simulated results across all frequencies. In average of all formulae the relative difference of calculated RTs at mid frequencies using calibrated and standard absorption coefficient was of about 37%.

CONCLUSIONS

The results in this paper suggest that when predicting reverberation time in cases of unevenly distributed absorption, no one of the classical formula may predict RT reliable within a accuracy in average of 10%. Using standard absorption data yield for classical formulae in most cases too short RTs. The Fitzroy formula and the model of Annex D of prEN 12354-6 yield too high RT values.

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