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Short Communication

Reverberation times and speech transmission indices in classrooms

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Abstract

Octave band reverberation times, background noise levels and speech transmission indices measurements were carried out in eighteen government subsidized primary and secondary schools in Hong Kong. Various normal classroom operation conditions were considered. Results illustrate that strong correlation exists between the reverberation times and the speech transmission indices regardless of the background noise levels and their NC values in the present study. The arithmetic average of the reverberation times in the 250 Hz to 4 Hz octave bands and the 1 kHz octave band reverberation time are found to be more important in the correlation in general. These findings provide a convenient mean for speech transmission design in classrooms.

1. Introduction

Classroom is a place where an individual is educated. When teachers communicate with or give instructions to the students in the classrooms, it is important that the messages can be passed effectively and clearly between them. Speech intelligibility is then of prime importance to the outcome of teaching, which affects the future development of the students.

Many indices for assessing speech intelligibility, such as the articulation index [1], speech transmission index (STI) [2] and the percentage articulation loss of consonants (%AL_{con}) [3] have been proposed. Bradley [4] has shown that there are significant correlations between these parameters, implying that they are equivalent.

The acoustical conditions in classrooms appear to have attracted worldwide attention [5,6]. A reliable prediction of the speech transmission quality in the design stage is therefore essential as any remedial action later on will be costly, disturbing and may even be impossible. However, the STI and other above-stated indices are difficult to predict. The only design data available are usually the amount of sound absorptions, thus reverberation times [7], and the background noise levels. A direct correlation between the reverberation times and the STI in the non-diffused conditions such as that in classrooms, is, to the knowledge of the

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authors, not well documented, though an estimation of the STI using known octave band reverberation times under the assumption of diffused sound field can be found in Houtgast et al. [8].

The present study documents an effort to test the relationships between the reverberation times and the STI in primary and secondary school classrooms whose architectural layouts are not acoustically diffusive. It is hoped that the present results can provide useful information for the improvement and assessment of the classroom acoustical quality in the design stage.

2. The classrooms and measurements

In the present study, site measurements were performed in 11 primary and seven secondary schools after school hours. A total of 58 classrooms were surveyed. They include general teaching rooms, computer rooms, music rooms and laboratories. In Hong Kong, the architectural layouts of the classrooms in the primary and secondary schools have standardized formats and the furniture provisions are also standardized (minor variations do exist). Table 1 summarizes the information of the classrooms which are relevant to acoustics. One can observe that the layouts of the classrooms become more and more standardized as time goes by.

Table 1
Summary of classroom facilities and layout

Design	Level	Classroom[a]	Dimensions[b]	A/C type	External landscaped	Acoustic treatment
Village	Primary	GT	$7.2 \times 8.9 \times 2.6$	Window type	Garden	False ceiling
		GT	$7.3 \times 7.0 \times 3.7$			False ceiling
		GT	$7.3 \times 7.0 \times 3.1$			Ceiling panel
Match-box	Primary	GT	$7.0 \times 7.0 \times 3.0$	Window type	Heavy traffic	Nil
		GT	$9.5 \times 7.0 \times 3.0$	Window type		
		GT	$6.5 \times 7.0 \times 3.0$	Split type		
		MU	$6.5 \times 10.0 \times 3.0$	Window type		
		MU	$6.0 \times 7.0 \times 3.0$	Window type		
		MU	$6.0 \times 7.0 \times 3.0$	Window type		
		CO	$7.3 \times 6.4 \times 3.0$	Window type		Carpet
		CO	$6.5 \times 11.5 \times 3.0$	Split type		Nil
		CO	$9.0 \times 7.0 \times 3.0$	Window type		Carpet
Link-wing	Secondary	GT	$10.0 \times 7.3 \times 3.0$	Window type	Light traffic	Nil
		GT	$9.0 \times 7.3 \times 3.0$	Split type	Heavy traffic	
		MU	$10.5 \times 9.0 \times 3.0$	Window type	Light traffic	
		MU	$6.5 \times 10.0 \times 3.0$	Split type	Heavy traffic	
		CO	$9.0 \times 5.2 \times 3.0$	Window type	Light traffic	
		CO	$7.0 \times 7.0 \times 3.0$	Window type	Heavy traffic	
		LA	$9.0 \times 10.6 \times 3.0$	Window type	Light traffic	
		LA	$9.7 \times 10.5 \times 3.0$	Split type	Heavy traffic	
Design 95	Primary	GT	$9.5 \times 7.3 \times 3.0$	Window type	Light traffic	Nil
		GT	$7.5 \times 7.4 \times 3.0$	Window type	Nearby school	
		GT	$7.5 \times 7.4 \times 3.0$	Split type	Nearby school	
		MU	$7.0 \times 7.0 \times 3.0$	Window type	Light traffic	
		MU	$11.0 \times 8.3 \times 3.0$	Window type	Nearby school	
		MU	$11.0 \times 8.3 \times 3.0$	Window type	Nearby school	
		CO	$7.0 \times 7.0 \times 3.0$	Window type	Light traffic	Carpet
		CO	$8.0 \times 7.7 \times 3.0$	Window type	Nearby school	
		CO	$8.0 \times 7.7 \times 3.0$	Split type	Nearby school	
	Secondary	GT	$8.0 \times 7.1 \times 3.0$	Window type	Nearby school	Nil
		GT	$8.0 \times 7.1 \times 3.0$			
		MU	$12.6 \times 7.5 \times 3.0$			Wood panel
		MU	$12.6 \times 7.5 \times 3.0$			
		LA	$11.1 \times 9.6 \times 3.0$			Nil
		LA	$11.0 \times 9.3 \times 3.0$			

Table 1 (*continued*)

Design	Level	Classroom[a]	Dimensions[b]	A/C type	External landscaped	Acoustic treatment
Design 2000	Primary	GT	$9.0 \times 7.0 \times 3.0$	Split type	Residential blocks	Nil
		GT	$9.5 \times 7.3 \times 3.0$			
		GT	$9.5 \times 7.0 \times 3.0$			
		MU	$7.0 \times 7.0 \times 3.0$	VRV		Porous panel
		MU	$7.0 \times 7.0 \times 3.0$			
		MU	$7.0 \times 7.0 \times 3.0$			
		CO	$7.0 \times 7.0 \times 3.0$	Split type		Carpet
		CO	$7.0 \times 7.0 \times 3.0$			
		CO	$7.0 \times 7.0 \times 3.0$			
		CO	$11.1 \times 7.9 \times 3.0$			
		CO	$11.1 \times 7.9 \times 3.0$			
	Secondary	GT	$9.2 \times 7.2 \times 3.0$	Split type		Nil
		GT	$9.2 \times 7.3 \times 3.0$	Split type		Nil
		GT	$9.0 \times 7.0 \times 3.0$	Fan coils		False ceiling
		MU	$7.0 \times 7.0 \times 3.0$	VRV		Porous panel
		MU	$7.0 \times 7.0 \times 3.0$			
		MU	$7.0 \times 7.0 \times 3.0$			
		CO	$7.0 \times 7.0 \times 3.0$	Split type		Carpet
		CO	$7.0 \times 7.0 \times 3.0$			
		CO	$7.0 \times 7.0 \times 3.0$			
		LA	$12.0 \times 9.0 \times 3.0$	Split type		Nil
		LA	$12.0 \times 9.0 \times 3.0$			
		LA	$12.0 \times 9.0 \times 3.0$			

[a]GT: general teaching; MU: music room; CO: computer room; LA: laboratory.
[b]Room dimensions in meter.

Carpets are usually found in the computer room and there are slight acoustic absorptions in the music rooms. The acoustic treatments in general teaching rooms and the laboratories, especially the latter, are very limited. The situations in the earlier designs show variations, but the acoustic conditions are reflected from the noise data presented later.

The measurements of the STI and the reverberation times from the 125 Hz to 8 kHz octave bands were done by the method of sound pulse decay implemented by the software DIRAC [9]. The sound pulses were created by popping inflated balloons at the mouth level of an adult at 1 m in front of the blackboard vertical centerline. The Brüel & Kjær Type 2260B sound level analyzer was located at nine equi-spaced locations at the ear level of the seated students in each classroom to measure the background noise spectra and to capture the sound pulse decay signals which were processed by DIRAC. The initial signal-to-noise ratios in all the important octave bands in the current study are not less than 35 dB, such that white noise pulses generated by the popping balloons are sufficient for reliable measurements.

3. Derived reverberation times

In building acoustic design, reverberation times in various octave bands are commonly used as the octave band material property data are very often available. Simple estimation of octave band reverberation times is therefore possible if the room geometry is simple and is fixed.

Human speech mainly spans over the frequency range from 250 Hz to 4 kHz octave bands [11]. Several broadband reverberation times are specifically defined in the present study. The first one is made consistent with the major speech frequency range:

$$\mathrm{RT}_{\mathrm{speech}} = (\mathrm{RT}_{250} + \mathrm{RT}_{500} + \mathrm{RT}_{1000} + \mathrm{RT}_{2000} + \mathrm{RT}_{4000})/5, \tag{1}$$

where the subscripts in the right-hand-side denote the center frequencies of the octave bands. One can define two reverberation times with reference to speech interference level (SIL) [7,10]:

$$\mathrm{RT_{SIL1}} = (\mathrm{RT}_{250} + \mathrm{RT}_{500} + \mathrm{RT}_{1000} + \mathrm{RT}_{2000})/4 \tag{2a}$$

and

$$\mathrm{RT_{SIL2}} = (\mathrm{RT}_{500} + \mathrm{RT}_{1000} + \mathrm{RT}_{2000} + \mathrm{RT}_{4000})/4. \tag{2b}$$

One can also recall the definition of the obsolete preferred speech interference level, which is still being used in the determination of the composite room criterion (RC) [11] and then defines

$$\mathrm{RT_{RC}} = (\mathrm{RT}_{500} + \mathrm{RT}_{1000} + \mathrm{RT}_{2000})/3. \tag{3}$$

Certainly, one cannot ignore the commonly used mid-frequency reverberation time

$$\mathrm{RT_{mid}} = (\mathrm{RT}_{500} + \mathrm{RT}_{1000})/2. \tag{4}$$

However, if one focuses on a single parameter for the description of sound absorption of an indoor space, the noise reduction class (NRC) [7] and the Sabine's formula suggest the consideration of a new reverberation time defined as

$$\mathrm{RT_{NRC}} = 4/(1/\mathrm{RT}_{250} + 1/\mathrm{RT}_{500} + 1/\mathrm{RT}_{1000} + 1/\mathrm{RT}_{2000}). \tag{5}$$

Though the definition of $\mathrm{RT_{NRC}}$ appears a bit complicated, it is useful in practical building acoustics calculations as sometimes only NRC will be available to design engineers. The octave band reverberation times, especially the RT_{1000} which is frequently used by researchers in the study of indoor speech transmission, are included in the foregoing analysis.

It should be noted here that the above-derived broadband reverberation times do not necessarily equal to the true reverberation times over the frequency ranges concerned, and thus may not bear any true physical meanings. They are introduced for practical purposes because there is no method in estimating the reverberation times within non-standard bandwidth in the design stage.

Geometric averages of octave band reverberation times, which have been adopted by Tang and Yeung [12], are not discussed here because the corresponding results are very similar to those obtained with the above arithmetic averages.

4. Results and discussions

Three tests with different room acoustic conditions have been carried out in each classroom basically. Table 2 summarizes these conditions and their immediate consequences to the room acoustics. One should be reminded that case C1 is not a normal operation mode of the classrooms in Hong Kong, except for a few days in winter when the air temperature goes below 10 °C.

Table 3 gives a brief summary of the acoustical conditions in Hong Kong schools. Results from all schools are not discussed separately as it is not the present scope to analyze the effect of architecture on the classroom acoustics. One can observe from Table 1 that these statistics will be biased to the new schools of the Design 95 and Design 2000 types. However, old schools here are being replaced gradually by the new school type which is a very standardized design so that the present results should be representative to the current classroom

Table 2
Descriptions of the cases considered

Case	Conditions	Consequences
C1	Window closed, air conditioning off	Acts as reference
C2	Window closed, air conditioning on	Background noise level increased Reverberation effect not much affected
C3	Window fully opened, air Conditioning off	Background noise level increased Reverberation effect reduced

Table 3
Summary of averaged classroom acoustical conditions

Classroom	Case	RT_{mid} (s)		BNL (dBA)		STI	
		Mean	S.D.	Mean	S.D.	Mean	S.D.
General teaching	C1	0.970	0.292	46.0	4.5	0.62	0.08
	C2	0.997	0.296	58.2	4.0	0.59	0.08
	C3	0.868	0.243	56.0	4.7	0.63	0.09
Music room	C1	1.008	0.448	47.2	3.7	0.62	0.09
	C2	1.004	0.442	57.2	3.4	0.59	0.10
	C3	0.869	0.370	54.9	4.8	0.63	0.09
Laboratory	C1	1.475	0.201	48.4	6.0	0.53	0.05
	C2	1.507	0.220	60.3	3.3	0.49	0.07
	C3	1.352	0.175	57.6	4.3	0.53	0.05
Computer room	C2	0.817	0.170	56.2	3.6	0.62	0.07

acoustics. The current situation is comparable to those in Hodgson [6]. In term of RT_{mid}, the situation here, though is not really satisfactory, appears to be better than those in Argentina observed by Ercoli et al. [13]. One can also notice from Table 3 that the laboratories on average have the longest reverberation due to the relatively more reflective room surfaces. The standard deviation of the RT_{mid} for the music rooms is the largest as the different surface treatments have been found during the survey. Such standard deviation is small when laboratories and computer rooms are concerned as the internal furnishings in these two kinds of rooms are very much standardized.

Figs. 1a–c illustrate the average background noise octave band spectra measured in the classrooms under the conditions C1–C3 respectively. The standard deviations of the band levels are very similar to those of the A-weighted background noise levels (Table 3) and thus are not presented. It can be observed that under condition C1, the mean octave band spectra in all kinds of classrooms are more-or-less similar though one can expect some variations from classroom to classroom. Individual spectra in this group are around NC40 $\pm$ 5 when the standard deviations are taken into account. Bigger difference can be observed under the condition of C2 (Fig. 1b). The individual spectra are of NC51 $\pm$ 5. For the cases of open windows (C3), collapse of average spectra is again observed (Fig. 1c). Apart from a broadband increase of band levels compared to the results of closed window cases (C1) shown in Fig. 1a, there is a slightly higher acoustic energy concentration in the 1 kHz octave band after opening the windows. One expects the noise will not be as steady as those under C1 and C2. This time, individual spectra are around NC50 $\pm$ 5.

The foregoing discussions focus on the relationships between the mean reverberation times and the mean speech transmission indices in individual classrooms under the three operation conditions adopted. A total of 152 mean data sets were involved. Figs. 2a–c illustrate the deviations of the STIs estimated using the assumption of diffused sound from the measured ones for the C1–C3 cases, respectively. For the case of closed window without air conditioning (C1), the diffused sound assumption results in slightly under-estimation of the STI. The standard deviation of the discrepancy, ε, of the estimation is just less than 0.02. Such error goes up to above 0.02 in the other two cases. It is expected that the deviation in the C2 cases is the largest due to the relatively high background noise level. The increase of the relatively low frequency rich background noise level appears to have larger effect on the deviation than the change in reverberation condition achieved by opening windows. One should also notice from Fig. 3, which shows the histograms of the residuals (measured minus estimated STI), that the distributions of the residuals are non-Gaussian. This tends to suggest higher probability of having error larger than the estimated ε is very likely, especially in the C1 and C3 cases. The errors in the C2 case are more-or-less uniformly distributed.

Fig. 4 shows that there are well-defined relationships between the room average STI and the room average RT_{speech} regardless of the usage of the classrooms, the background noise levels and the room operation conditions (C1–C3). It is not surprising that larger scattering of results is found under conditions C2 and C3

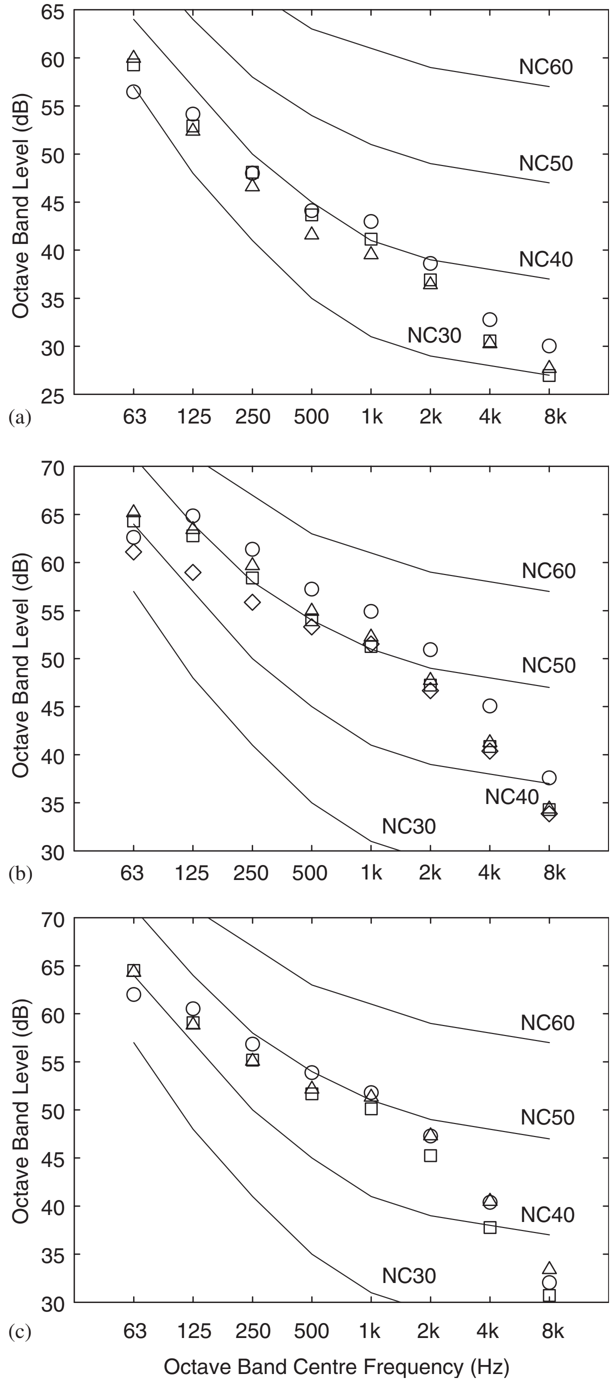

Fig. 1. Background noise levels under different operation conditions. (a) C1; (b) C2 and (c) C3. ○: general teaching rooms; ⩽: laboratories; △: music rooms; ◇: computer rooms; ———: NC curves.

where background noise levels do vary from classroom to classroom. Similar observations can be made for other octave band and derived reverberation times, except for the 125 Hz octave band ones. The high signal-to-noise ratio in the present study is believed to be one of the reasons for the good correlations. This will be discussed further later.

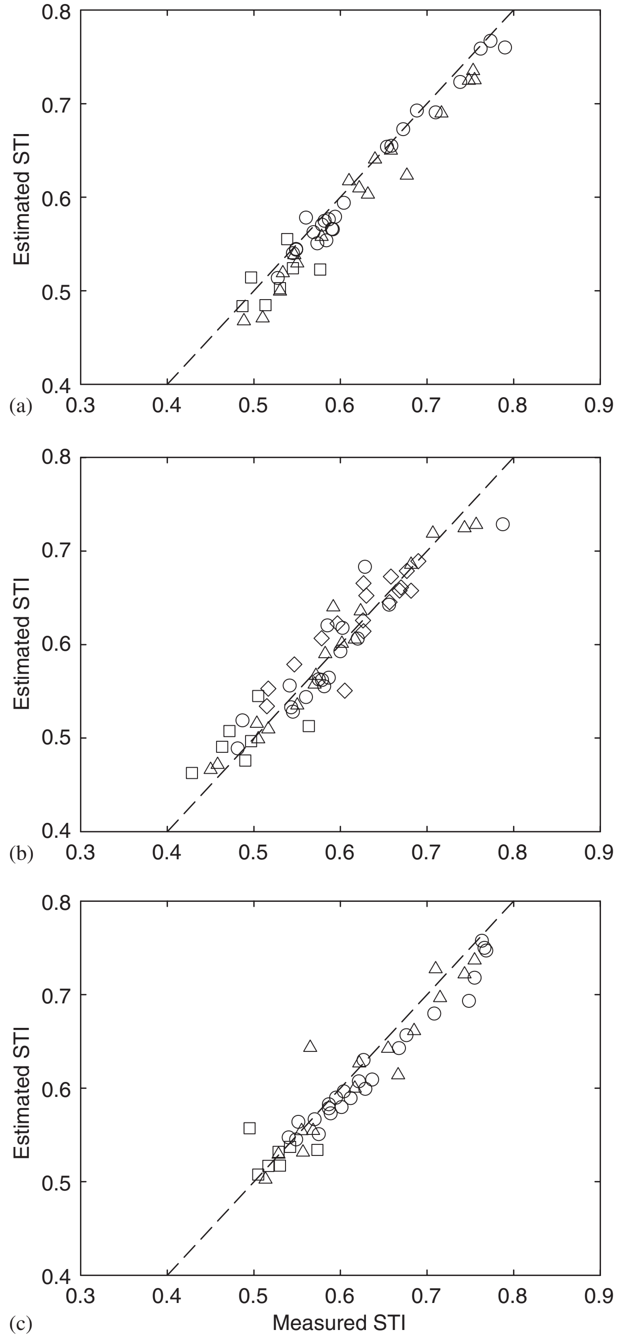

Fig. 2. Discrepancy between measured and estimated room average STI. (a) C1; (b) C2; (c) C3. ○: general teaching rooms; ⩽: laboratories; △: music rooms; ◇: computer rooms; ———: line for measurement equals estimation.

A trial on using 100 simple curve types to correlate with the present measurements has been carried out. Owing to the length limit of this paper, the statistical test results on the goodness-of-fit of these 100 simple curve types are not presented. The 'best fit' curve type when all the data are considered appears to be

$$\sqrt{\mathrm{STI}} = a + b\,\exp(-\mathrm{RT}), \tag{6}$$

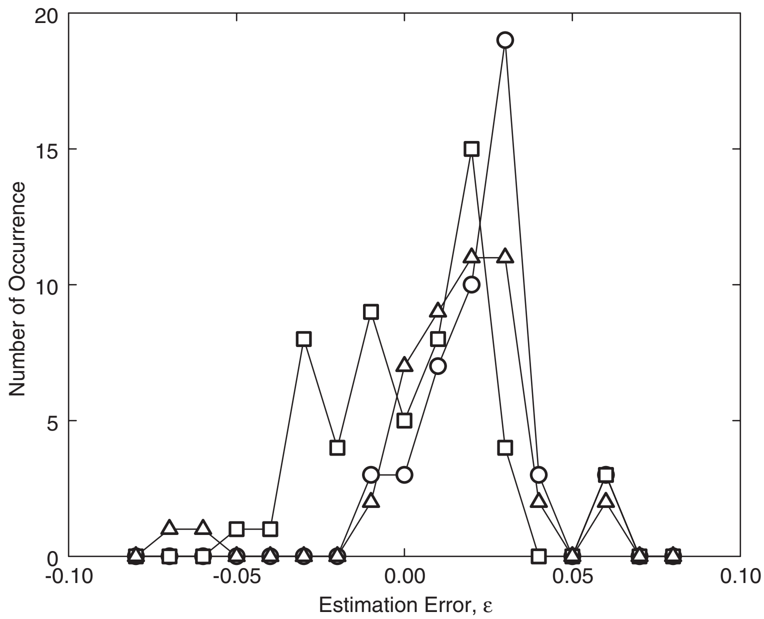

Fig. 3. Distributions of room average STI estimation errors. ○: C1; ⩽: C2; △: C3.

where a and b are positive constants. These regression lines are also included in Fig. 4. However, the goodness-of-fit for the first ten best correlation curve types are actually very similar, but some of them, such as the one in Tang and Yeung [12], are not physically sound. The residuals of the regression are Gaussian distributed.

Table 4 illustrates that the correlation between the average STI and mean reverberation time is very strong inside the classrooms under C1 regardless of the definition of the latter. The corresponding results for the 125 Hz and 8 kHz octave bands are not included as they are not expected to be very important in the topic. As expected and demonstrated by the results concerning with C1–C3, the goodness-of-fit decreases as the background noise level increases. The present results suggest that most of the derived reverberation times perform well in correlating with the measured STI for the C1 case, where a longer reverberation and lower background noise are found. In general, the derived reverberation times RT_{speech} and RT_{SIL2} appear to be slightly more useful in the assessment of the sound transmission quality inside all the classrooms survey. For convenience, the RT_{1000} can be considered as a quick mean of the checking. Under higher level of continuous background noise (C2), there is no difference in the performance of the derived reverberation times.

One can also notice from Table 4 that the regression form of Eq. (6) suggests $STI \rightarrow 1$ when $RT \rightarrow 0$ which is physically justifiable. This is especially true for the C1 and C3 cases, but the regression results under the C2 case do suggest $STI > 0.9$ in the anechoic condition. The high signal-to-noise ration in the present study appears again to be the main reason for this. For long reverberation condition, the regression curve still suggests an average $STI > 0.6$ for all classroom conditions. This may only apply to the present acoustical conditions in the classrooms (Table 3).

Direct regression analysis of individual pairs of reverberation times and speech transmission indices in general produces conclusions very much similar to those obtained with room averages. Therefore, the corresponding data are not presented.

It has been mentioned that the derived reverberation times in the present study do not bear any real physical meaning, but it has been shown that they exhibit significant correlations with the measured sound transmission indices. The STI, as shown in Houtgast et al. [8], is estimated from octave band modular transfer functions, which depend on the impulse responses of a classroom in different octave bands from 125 Hz to 8 kHz. The present observation under a high signal-to-noise ratio therefore tends to suggest that similarity exists between these impulse responses, leading to significant correlations between the apparent signal-to-noise ratios.

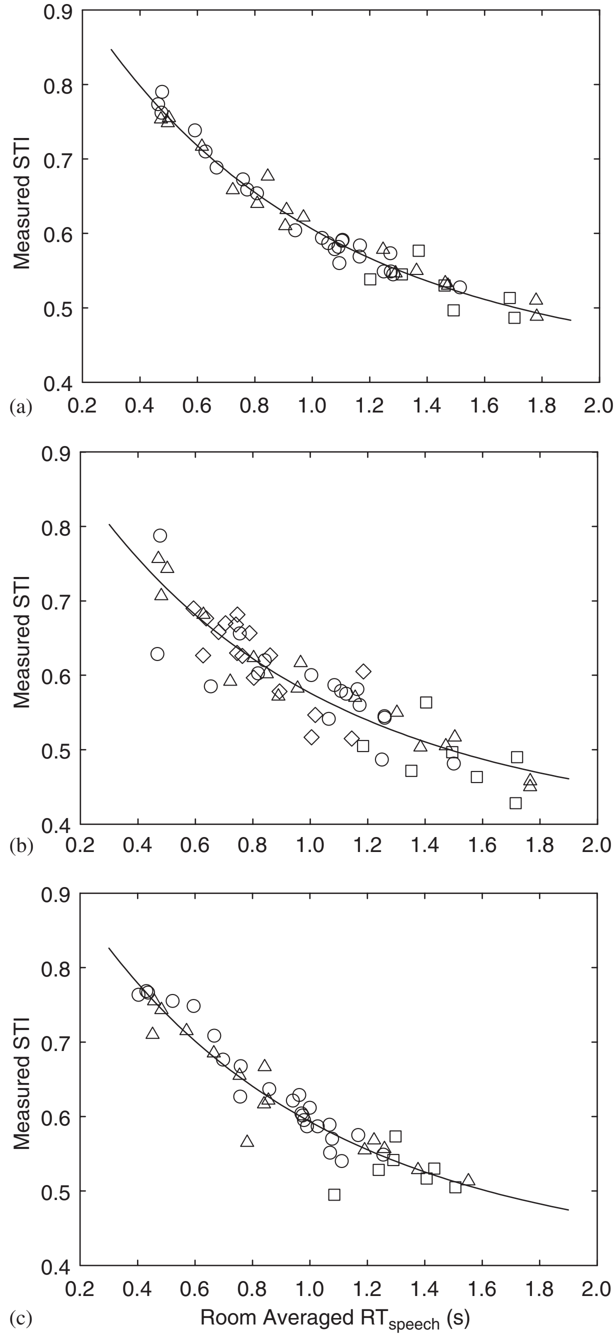

Fig. 4. Correlations between room average RT_{speech} and room average STI. (a) C1; (b) C2; (c) C3. ○: general teaching rooms; ⩽: laboratories; △: music rooms; ◇: computer rooms. ———: regression lines $\sqrt{STI} = a + b\exp(-RT/RT_o)$, $RT_o = 1$ s.

Fig. 5 illustrates the significant correlations between the octave band reverberation times in the present study, though that concerning with RT_{250} is not as good. Even better correlations are found when the room averages are concerned (not shown here). This indicates indirectly the existence of similarity in the room impulse responses. It is conjectured that this phenomenon is due to the building materials and the nominally rectangular layouts of the classrooms. One can then anticipate that there will be significant relationships

Table 4
Correlations between room averaged STI and room averaged reverberation times (Regression formula adopted: $\sqrt{\mathrm{STI}} = a + b \exp(-\mathrm{RT}/\mathrm{RT}_o)$, RT = 1 s)

Case	Reverberation time	R^2	Standard error	a	b	$\mathrm{STI}_{\mathrm{RT}=0\mathrm{s}}$
C1	$\mathrm{RT}_{\mathrm{speech}}$	0.97	0.014	0.6383	0.3806	1.04
	$\mathrm{RT}_{\mathrm{SIL1}}$	0.97	0.015	0.6431	0.3776	1.04
	$\mathrm{RT}_{\mathrm{SIL2}}$	0.97	0.014	0.6372	0.3680	1.01
	$\mathrm{RT}_{\mathrm{mid}}$	0.96	0.017	0.6435	0.3612	1.01
	$\mathrm{RT}_{\mathrm{RC}}$	0.97	0.015	0.6427	0.3616	1.01
	$\mathrm{RT}_{\mathrm{NRC}}$	0.97	0.015	0.6435	0.3714	1.03
	RT_{250}	0.87	0.031	0.6562	0.3906	1.10
	RT_{500}	0.94	0.021	0.6410	0.3725	1.03
	RT_{1000}	0.97	0.015	0.6470	0.3465	0.99
	RT_{2000}	0.96	0.017	0.6441	0.3534	1.00
	RT_{4000}	0.95	0.019	0.6211	0.3824	1.01
C2	$\mathrm{RT}_{\mathrm{speech}}$	0.82	0.034	0.6240	0.3670	0.98
	$\mathrm{RT}_{\mathrm{SIL1}}$	0.83	0.034	0.6287	0.3634	0.98
	$\mathrm{RT}_{\mathrm{SIL2}}$	0.82	0.034	0.6226	0.3573	0.96
	$\mathrm{RT}_{\mathrm{mid}}$	0.82	0.034	0.6282	0.3513	0.96
	$\mathrm{RT}_{\mathrm{RC}}$	0.82	0.034	0.6278	0.3511	0.96
	$\mathrm{RT}_{\mathrm{NRC}}$	0.82	0.034	0.6291	0.3575	0.97
	RT_{250}	0.74	0.041	0.6453	0.3597	1.01
	RT_{500}	0.81	0.035	0.6288	0.3510	0.96
	RT_{1000}	0.82	0.035	0.6306	0.3439	0.95
	RT_{2000}	0.80	0.036	0.6308	0.3407	0.94
	RT_{4000}	0.78	0.038	0.6090	0.3682	0.95
C3	$\mathrm{RT}_{\mathrm{speech}}$	0.91	0.025	0.6332	0.3722	1.01
	$\mathrm{RT}_{\mathrm{SIL1}}$	0.90	0.026	0.6387	0.3671	1.01
	$\mathrm{RT}_{\mathrm{SIL2}}$	0.97	0.024	0.6311	0.3655	0.99
	$\mathrm{RT}_{\mathrm{mid}}$	0.89	0.027	0.6389	0.3557	0.99
	$\mathrm{RT}_{\mathrm{RC}}$	0.90	0.025	0.6373	0.3577	0.99
	$\mathrm{RT}_{\mathrm{NRC}}$	0.90	0.026	0.6382	0.3643	1.01
	RT_{250}	0.79	0.037	0.6571	0.3551	1.02
	RT_{500}	0.87	0.030	0.6373	0.3605	1.00
	RT_{1000}	0.91	0.025	0.6417	0.3465	0.98
	RT_{2000}	0.91	0.024	0.6376	0.3530	0.98
	RT_{4000}	0.90	0.025	0.6143	0.3821	0.99

between various speech-related acoustical parameters, which also depend basically on the impulse responses [4]. This is left to further investigation.

5. Conclusions

In the present study, a survey of the speech transmission quality was carried out in the classrooms of 18 government subsidized primary and secondary schools in Hong Kong. Many of them are of standardized architectural designs, but all classrooms are acoustically non-diffusive. Several derived reverberation times are introduced and their performance in correlating with the sound transmission indices is investigated.

The relationships between various reverberation times and the speech transmission indices do not appear to depend on the functions and operating conditions of the classrooms and the NC values. Regression analysis favors a linear relationship between speech transmission indices and the exponential of reverberation times. The degree of the correlation decreases as the background noise level increases. Among the derived reverberation times studied, the arithmetic averages over the 250 Hz to 4 kHz octave bands and those over the 500 Hz to 4 kHz octave band appear to be slightly better than the others to correlate with the speech

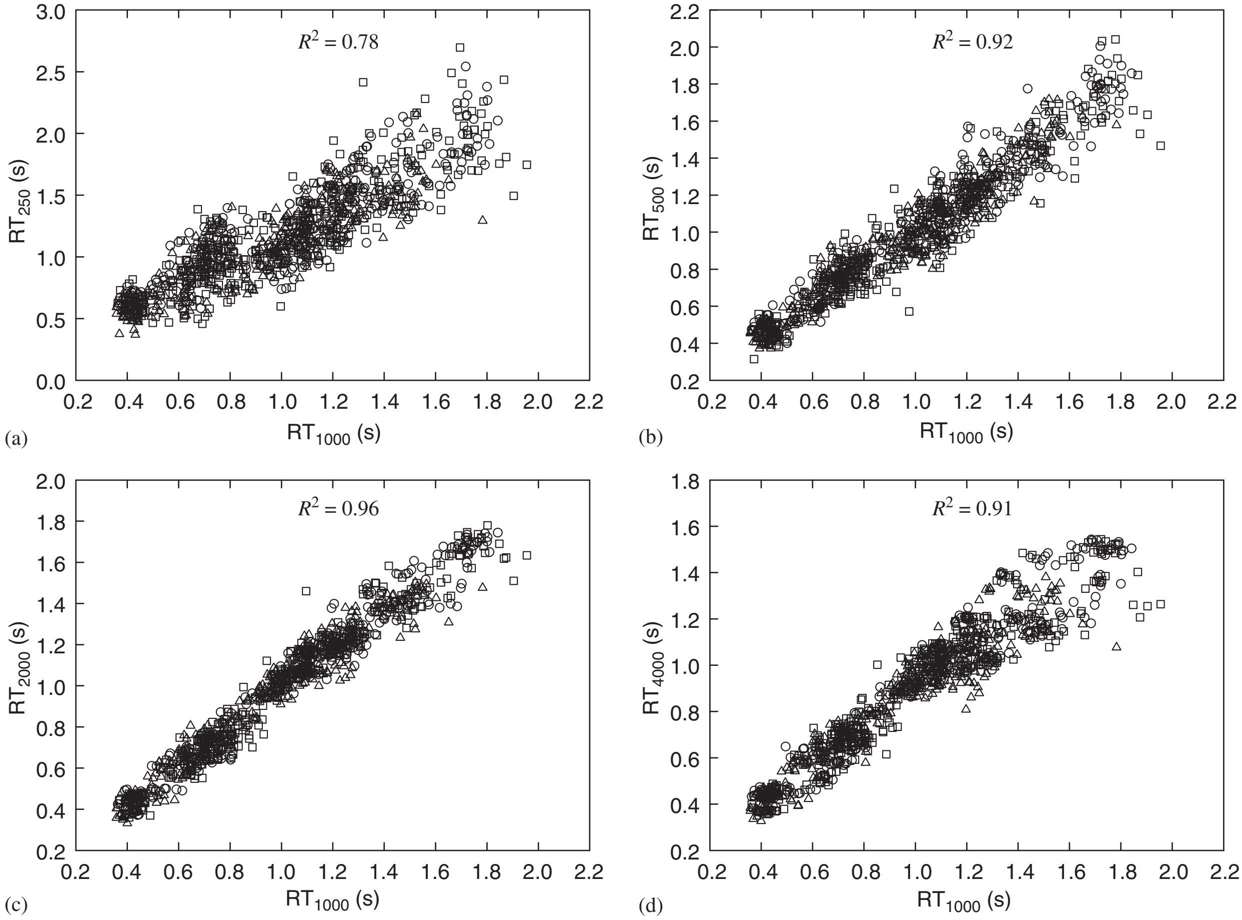

Fig. 5. Correlations between octave band reverberation times with RT_{1000}. (a) RT_{250}; (b) RT_{500}; (c) RT_{2000}; (d) RT_{4000}. ○: C1; $\leqslant$: C2; △: C3.

transmission indices. It is shown that the 1 kHz octave band reverberation time can act as a quick assessment of the speech transmission quality in the classrooms.

The good correlations between the derived reverberation times and the sound transmission indices and the favorable comparison of the regression standard errors with the errors of estimating the sound transmission indices using the diffused sound field assumption manifest the usefulness of these parameters in the design for speech transmission quality inside the classrooms.

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