Improving Speech Intelligibility in Classrooms by Decreasing Sound Energy of Low Frequency

Wei Lin[1(✉)], Hsuan Lin[2], and Kung-Huang Huang[3]

[1] Department of Interior Design, Hwa Hsia University of Technology, Taipei, Taiwan
weilin@cc.hwh.edu.tw
[2] Department of Product Design, Tainan University of Technology, Tainan, Taiwan
te0038@mail.tut.edu.tw
[3] General Manager, Shang You Construction Co. Ltd., Kaohsiung, Taiwan
sf.land@msa.hinet.net

Abstract. Speech intelligibility is one of the sound field quality evaluation criteria, class-room space needed to create a low-noise and clear listening environment. In addition to the reverberation time (sec), chamber volume (m3) and speech clarity (dB) can tolerate higher use of space and other influencing factors of critical sound energy at low frequency, the spatial frequency factor for indoor conversation came the noise amplification effect will affect listening clarity. Evaluative standard of Rapid Speech Intelligibility (RASTI) for an indoor sound field has been studied for a long time, only 500 Hz and 2 K-Hz cannot be precisely estimated the impact of low frequency noise. After making a Chinese phase and sentence questionnaire for the test, studies will be conducted objective and subjective verification verified statement containing the real class-room space by physical quantities (Reverberation time (RT30, sec) and Signal to noise ratio (S/N ratio, dB) of low-frequency sound energy is correlated be-tween with objective measurement, and subjective test of virtual classrooms is also be made in anechoic chamber to correspond with the low frequency impact factor of speech intelligibility index.

Keywords: Speech intelligibility · Low frequency of sound energy · Virtual sound field · Subjective test

1 Introduction

Classroom acoustics is the research point for room acoustics filed, effective factors of analysis for speech intelligibility and improvement of environment for the classroom acoustic is another subjective sense of current studies. The objective parameters influence speech intelligibility which included chamber's volume, the reverberation time, the signal to noise ratio, the speaker's voice level and talker-to-listener distance. Although the Reverberation time and signal to noise ratio are the most commonly discussed, low frequency sound energy range correspondence with signal to noise ratio

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and the reverberation time in the classroom assessment may not have consistent results [1, 2].

Impulse response of the signal are obtained through by processing software and can also be produced by changing the actual sound impulse response. By the signal processing of the different adjustments, resulting in the ideal value of the parameter corresponding to a combination of low-frequency factors, and further the sound field to discuss the proper signal to noise ratio and reverberation time. Many studies have found that the impulse response of the sound field are adjusted the reflection density through the differences of room volume, and then achieve a different reverberation time by adjusting the amplitude and attenuation rate [3, 4]. Even if reverberation time are the same, the density of amplitude reflection are the difference [5]. Current assessment parameter (RASTI) at indoor sound field for speech intelligibility is a comprehensive physical evaluation which is mainly discussed at the band of 500 Hz and 2000 Hz. It may not clearly show contours at the low frequency band of sound field conditions. Through digital signal processing, correlation between the subjective experiment and the objective evaluation of the results on the current trend may also be conducted by tuning the low frequency elements.

1.1 Effect of Low Frequency's Element on Theory of Speech Signal

Low frequency impact on speech signals in a voice message expression is a critical issue, since the high-frequency elements on the voice pronunciation have been concentrated as the main octave band, high frequency octave band have been discussed more than low frequency. This leads to interference noise suppression efforts in the high-frequency band, but to ignore the low-frequency band caused by a more serious factor of the shadowing effect. By German linguist Slawin [6] studies, f1 effect will be generated a multi-level sense of hearing additional harmonics in strong signal frequency, as shown by the following Eq. 1.

$$f = (\mathrm{n}+1)\,\mathrm{Fi}; \quad \mathrm{n} = 1,\, 2,\, 3, \ldots \tag{1}$$

When multiple strong signals f1 and f2 simultaneously act, in addition to the respective homophonic will occur, it will also produce a "Aggregate homophonic": as shown by the following Eq. 2.

$$fK = nf1 \pm mf2; \qquad m = 1, 2, 3, \ldots \tag{2}$$

The auditory organs get additional sounds, calling the "subjective homonym", it is interesting a sense of hearing homonym that cannot be presented by the measurement in a real environment. The numbers of homophonic sense of hearing increase the energy of the sound field with the actual sound level which are also in disproportionate. In subjective sense of hearing, when the low frequency of sound energy is higher than 80 dB, the sense of hearing harmonics of phonics articulation at high frequency feel strongly than the fundamental ones. As in the bass strings when toggle, the sense of hearing of harmonics sound is more active than fundamental sound energy. When powerful tone or noise sound caused by echoes of sound energy of nonlinear superposition, listening masker of high frequency acoustic energy may occur, especially for speech intelligibility, masking effects in high frequency band is more severe. The University of Göttingen professor Hellbrueck's study [7] found that, strong low-frequency acoustic masked the feeling of the high-frequency hearing, and despite the high-frequency sound enhance, it is not easy to improve the intelligibility of subjective judgments due to the low frequency sound energy shaded. Furthermore, if the obscured low-frequency and obscured high-frequency signals arrive simultaneously in one ear, unintelligibility of hearing can be more severe. It also shows that if the hearing-impaired friends are in the crowded reception space, even if wear the functional hearing aids, they are still extremely uncomfortable [8]. By German National Research Center IBP acoustic researcher [9] further confirmation, subjective experiments of German syllable intelligibility, experiments results may have a severe interference through 20 Hz–20 kHz broadband pink noise. In all evaluation of the results of those tests, if the frequency of the sound-absorbing material considerations as low as 50 Hz are installed in the test chamber while scores of its higher speech intelligibility may occur, and listening comfort may also improve.

1.2 Control Background Noise in Classroom

Control of self-generated noise in the classroom is an important issue, and requirements of general use of language-based indoor background noise is 40 dB (A) or less. High relative quiet background noise in the classroom, talking to each other in the process (at 1 m distance) can be achieved in the state of relaxed conversation and achieve good speech intelligibility. When the increase or enlarge classroom speakers voice happen, it also means that the noise criteria of sound field move to a noisy indication. In terms of direct experience of the listeners receive the average loudness of sound energy and stability of sound source, classroom sound power level *Lw* as shown in Eq. 3:

$$Lw = Lw - 10\mathrm{lgV} + 10\mathrm{lgT} + 14\mathrm{dB} \tag{3}$$

Lw is stand for sound power, V is stand for chamber volume (m3), T is for the reverberation time (s)

When a single talker speak in the classroom (sound power *Lw*), speaker himself feel volume boost due to noise factor, subjective perception of speaker think that listeners can clearly hear his voice words, and thus understand its discourse content, then *Lw* as shown in Eq. 4:

$$Lw = \mathrm{Lw} + 10\mathrm{lg}n - 10\mathrm{lgV} + 10\mathrm{lgT} + 14\mathrm{dB} \tag{4}$$

In the Formula 4, 10 lg n stand for multiple noise sources and amplification, the hearing threshold of entire spectrum will cause increase. In Reverberation time formula (RT), the same acoustic energy in the corresponding multiples enlarge chamber volume, due to the secondary path of the reflection sound energy also will multiply, with increasing reverberation time. Appropriate reverberation time in the chamber can improve speech intelligibility, however, due to the height of 3.5 m ~ 4 m Classroom restrictions and noise will amplify sound energy at low frequency, and high frequency shadowing effects become more significant. If the speech sound power increase, as Lw = 80 dB (A), and assuming that the direction of the sound source characteristics of 10 lg v = 3 dB, r indicates the distance the sound source, the following equation (Eq. 5) can be expressed in sound power *Lw*:

$$Lw = \mathrm{Lw} + 10\mathrm{lgV} - 20\mathrm{lgr} - 11\mathrm{dB} \tag{5}$$

For the speech transmission, listeners need to perceive speech intelligibility, which is generated by the sound energy of increasing talker sound level higher than the background noise. Within the corresponding German Standards Institute [10] for speech intelligibility, difference of interference level (12 dB to -6 dB), the sound power level and the distance between the sound source, the proposed space allow sound level shown as in Table 1.

Table 1. DIN 18041–2004 (German Standards Institute [10]) proposed space allow sound level as function which are evaluated by speech intelligibility, difference of interference level (12 dB to – 6 dB), the sound power level and the distance between the sound source.

Talker sound power, *Lw* dB (A)	Speech Intelligibility: Excellent (12 dB)			Good (6 dB)			Fair (0 dB)			Bad (-6 dB)		
	0.5 m	1 m	2 m	0.5 m	1 m	2 m	0.5 m	1 m	2 m	0.5 m	1 m	2 m
	Allowed sound level dB(A)											
62	48	42	36	54	48	42	60	54	48	66	60	54
68	54	48	42	60	54	48	66	60	54	72	66	60
74	60	54	48	66	60	54	72	66	60	78	72	66
80	66	60	54	72	66	60	78	72	66	84	78	72

High quality classroom space is the creation of high-definition voice environment, for the theory of the influence of the voice signal can be seen from the low-frequency, high frequency sound energy as if by a powerful low-frequency interference signals can affect the sound, the subjective high frequency sound energy will be obscured due to the superposition of the hom-onym. Under consideration of the self-generated noise control in classroom, the usage of speech-based indoor background noise control requirement is at 40 dB (A) or less.

The purpose of this study is to establish the low-frequency factor for understanding the in-fluence of speech intelligibility in classroom, based on objective parameters of the sound field data, effect factors of subjective evaluation and corresponding with multi-dimensions of con-sistency would have discussion. Research steps are divided into three parts, the first phase of the field measurement of parameter performance on the space of the classroom have been collected, and the classroom located at the National Taitung University which is as the proto-type of virtual sound field for next stage. The second phase will be the impulse response of field classroom has been collected, through a subjective assessment to discuss the degree of obscured sound at low frequency band for the sense of hearing for speech intelligibility. Dry source are accomplished with phonics list which is using by a digital signal recording in ane-choic chamber, modification using the digital impulse response of different chamber volume are been conducted, and then create multiple sets of different classroom sound field by taking into consideration the different combinations of signal to noise ratio and reverberation time. After completion of convolution with read paragraph (Dry source) in different groups of sound source, subjective test samples with different conditions of the sound field are also obtained. The third phase is to take a subjective hearing test which the test segments is made of many groups of sound field voice, and compared with the actual filed subjective test consistency.

2 Previous Research Works

Standard classroom type at National Taitung University is as the verification space, renovation in the original open classroom is also be conducted in order to modify the effect of sound energy at low-frequency band which may meet the room acoustical design as the main tar-get. The picture image of renovated classroom at National Taitung University is shown in Fig. 1. Total area of interior floor was 100 m^2 and the basic conditions for classroom space are shown in Table 2. The performance of the reverberation time yielded by adjusting the use of sound-absorbing material, and consider the full frequency high sound absorption rate, especially for the absorption properties of low-frequency is the main choice direction. The micro perforated plates and melamine foam are used as a broadband application of sound absorption material, each absorption coefficient of 1/1 center octave band is shown in the Table 3.

Table 2. Construction conditions of real classroom space

Function	Classroom
Room type	Rectangular shape
Room size	Width × Length × High: 12.9 m × 7.8 m × 3 m
Volume	100 M^3
Absorption material	Melamine foam and micro perforated plates

Table 3. Table of material absorption coefficient of 1/1 center octave band are listed

Material (Thickness)	125 Hz	250 Hz	500 Hz	1 K Hz	2 K Hz	4 K Hz
Melamine foam (2 M)	0.14	0.17	0.42	0.68	0.88	0.92
Melamine foam (5 M)	0.25	0.65	1	1	1	1
Micro perforated plates (10CM)	0.15	00.45	0.78	0.90	0.57	0.58
Micro perforated plates (20CM)	0.25	0.71	0.92	0.56	0.58	0.56
Micro perforated plates (30CM)	0.53	0.78	0.65	0.70	0.60	0.55

Fig. 1. Renovated Standard classroom type at National Taitung University

3 Methodology

The first phase of the field measurement of classroom performance on the parameter has been collected. As a result of the physical quantity measured objectively in the classroom, RASTI shows a little significant difference between the original mode and renovated mode. If the evaluation results of speech intelligibility determined by the RASTI directly, it will ignore the impacts caused by the low frequency of sound. In order to effectively understand the impact of low frequency factor of speech intelligibility, investigation of differences of correspondence between the subjective evaluation and the objective measurement were also con-ducted. And in the previous phase measurement of classroom space (prototype) for the second phase of the modified one was the virtual sound field. Finally, the third stage explored a consistency and comparisons a sense of subjective tests between the virtual field and real field were considered.

3.1 Syllable Table for Subjective Test

Preliminary study, based on the Chen's [11] research, the production of speech syllable table of Chinese words and sentences (meaningful) were completed. Due to the 1198 syllables in the actual application of testing, avoid to lead to the difficulties by utilizing a stratified probability sample (stratified sampling) way was conducted, and the computer "random" the same amount of sampling six syllables was also yielded, made a total of 108 syllables as a single sample of the sound which might consist sort of a sets of words and sentences table.

3.2 Reproducibility of Virtual Sound Field

The actual collection of the impulse response of the classroom were placed through the sound effect system with ambient noise, the impulse response of the classroom field measurement was collected by the digital signal station, the reverse function integration of Schroeder's proposed use of function [12] was also obtained integral curves of the reverberation time.

3.3 Completion of Subjective Test with Virtual Classroom

The Chinese continuous speech of continuous meaningful female voice of test table (maskee1) table have been accomplished which were recorded in the anechoic chamber, then recorded test tables were edited by using by FFT signal processing software, Sound forge7.0 version. Dry source voice sample convolution (Convolution) was placed the classroom sound field which got a different sound field conditions such as three groups of signal to noise ratio of, three groups of low-frequency and three group of sound reverberation time in combination with a segment group of 27 field samples were available. To make sense of hearing the result of differences effectively, avoid to excessive combinations of subjective test caused by invalid, re-downsizing the number of combinations to 9 samples formed is listed in the Table 4. With the results shown in Table 4, three groups of reverberation time (0.55 s, 0.85 s and 1.15 s) and three groups of signal to noise ratio (0 dB, +6 dB and +15 dB) combination of different sound field environment, explore the results of impacts by the three groups of low frequency sound (125 Hz, 63 Hz and 50 Hz). Sample of a subjective test track is shown in Fig. 2, speech convolution with signal to noise ratio (+ 6 dB) is calculated which explore sound at low frequency band (63 Hz) of hearing response in virtual classroom of the reverberation time of 1.15 s sound field.

Fig. 2. The subjective test tracks with signal to noise ratio (+ 6 dB) are calculated which explore sound at low frequency band (63 Hz) of hearing response in virtual classroom of the reverberation time of 1.15 s sound field.

Table 4. Combination with a segment group of 9 field samples were available

		Reverberation Time T30 (s)		
		0.55 s	0.85 s	1.15 s
S/N ratio(dB)	0 dB	125 Hz		
	+6 dB		63 Hz	
	+15 dB			50 Hz

4 Discussion

The purpose of this study is to establish the low-frequency factor for understanding the in-fluence of speech intelligibility in classroom, based on objective parameters of the sound field data, effect factors of subjective evaluation and corresponding with multi-dimensions of con-sistency would have discussion. Research steps are divided into three parts, the first phase of the field measurement of parameter performance on the space of the classroom have been collected, and the classroom located at the National Taitung University which is as the proto-type of virtual sound field for next stage. The second phase will be the impulse response of field classroom has been collected, through a subjective assessment to discuss the degree of obscured sound at low frequency band for the sense of hearing speech intelligibility.

4.1 Field Verification with Measurements

Acoustical measurements using an aural tone speaker were followed by a objective study comparing future subjective test with recorded sound in classroom (Code 105), National Tai-tung University. The 100-m2 of floor area provided a space for listeners. The location of a microphone receiver at the audience seats have to be placed average distribution in class-room. Acoustical measurements were taken using the B&K Dirac software package, from which ISO standard measures were also conducted. An e-sweep sine signal was emitted from at a height of 1.5-m Auratone 4-inch speaker aimed at an elevation angle of 0 º. Di-rectivity of characteristics for the Auratone 4-inch speaker was measured in anechoic chamber in National Taiwan University of Science and Technology. The speaker was placed on central axis at 2 m from the stage platform line was supported on a tripod at 1.5 m above the floor.

4.2 Results on the Field Verification

Figure 3 shows T30 (Reverberation time) taken the 0 º azimuth angles with the speaker aimed frontally. The data from the original mode and from renovated mode are averaged. The difference of T30 between the original mode and renovated mode of classroom was 30 % decreases for frequency bands 31.5 Hz through 63 Hz. The value was close to 1.0 s at the renovated mode after the absorption material installed. There was a little difference be-tween the 2 Modes when evaluated the parameter of speech intelligibility (RASTI), which was close 0.65 corresponding with the subjective evaluation indicate (Good).

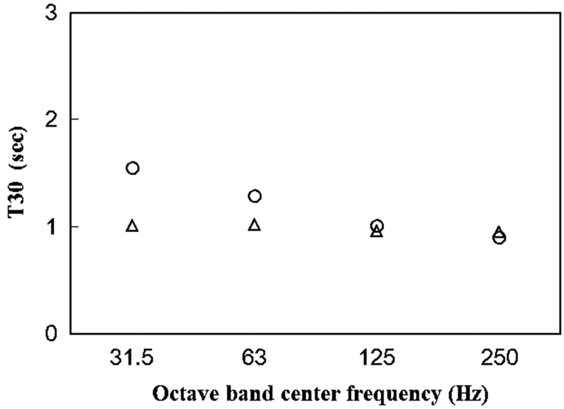

Fig. 3. Reverberation time (T30) as a function of frequency bands 31.5 Hz through 250 Hz comparing original mode (○) to renovated mode (△).

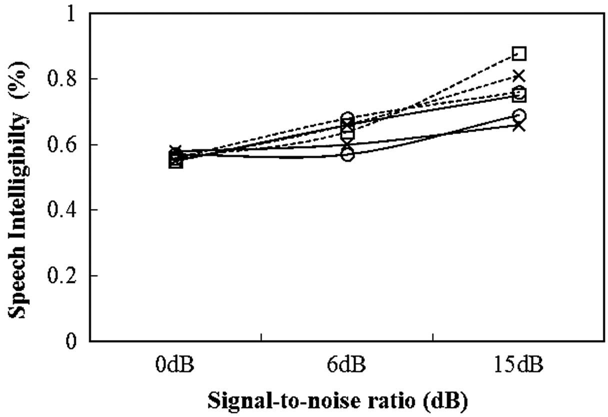

Fig. 4. Two groups reverberation time (0.55 s(—) and1.15 s(____)) and three groups of signal to noise ratio (0 dB, +6 dB and +15 dB) combination of different sound field environment, explore the distribution of subjective test (speech intelligibility)by the three groups sound at low frequency band (125 Hz(○), 63 Hz(╳) and 50 Hz(□)).

Subjective experiment was carried out through headphones at acoustical laboratories of Hwa Hsia Institute of Technology, simulation the scene of fidelity was also be conducted which the scenario image of classroom of National Taitung University might been projected during the test. Surveying the questionnaire tests were evaluated which the content of words and sentences are meaningful. Three groups of reverberation time

(0.55 s, 0.85 s and 1.15 s) and three groups of signal to noise ratio (0 dB, +6 dB and +15 dB) combination of different sound field environment, explore the results of impacts by the three groups sound at low frequency band (125 Hz, 63 Hz and 50 Hz). It was found that the high value of signal to noise ratio (S /N ratio) may effectively enhance the results of subjective evaluation, however, the difference among combination of reverberation time (T30) is not significant difference (correlation coefficient r = 0.28). Test results on speech convolution with signal to noise ratio (+ 15 dB) and low frequency band (50 Hz) of hearing response in virtual classroom of the reverberation time of 0.55 s sound field may obtain the highly scores. See the Fig. 4.

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