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Initial Study on the Reverberation Time Standard for the Korean Middle and High School Classrooms Using Speech Intelligibility Tests

Chan-Jae Park and Chan-Hoon Haan *

Department of Architectural Engineering, Chungbuk National University, Cheongju 28644, Chungbuk, Korea; cjpark@cbnu.ac.kr
* Correspondence: chhaan@cbnu.ac.kr

Abstract: The most important function of the classroom is to transmit educational information from teachers to students more accurately and clearly. The acoustical environment of the classroom thus has an important effect on the improvement of students' learning ability. To provide an appropriate acoustical environment for learning to students, it is necessary to create an acoustical performance standard for classrooms and a guideline for designing classrooms. However, in Korea, there is not an acoustical standard for classrooms; thus, it is difficult to control and manage appropriate acoustical performance when designing and building classrooms. The present study aims to suggest acoustic performance standards for classrooms that are suitable for the Korean language. In order to perform this study, standard classrooms were created by standardizing architectural dimensions of 17 middle and high school classrooms in Cheong-ju. Speech intelligibility tests were conducted using three different languages including Korean, English, and Chinese. Twenty native speakers for each language were used as subjects for the speech intelligibility tests. Finally, auralized sound sources were created with five different conditions of reverberation time (0.47~1.22 s) by changing indoor sound absorption of a real classroom. Listening tests were undertaken by 52 Korean adults with normal hearing, using the auralized sound source. The results proved that the most appropriate reverberation time for learning was above 0.76 s. Based on the research findings, the ideal acoustical performance standard for classrooms in Korea is as follows: background noise is below 35 dBA, and reverberation time is below 0.80 s. It is also necessary that indoor sound absorption should be above 20% without sound absorption on side walls in order to satisfy with the acoustical performance standard.

Keywords: acoustical standard; Korean classroom; auralization; speech intelligibility test

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1. Introduction

The most important function of the classroom is to transmit educational information from teachers to students more accurately and clearly. Acoustical environment of the classroom thus has an important effect on the improvement of students' learning ability. An initial study on classroom acoustics concentrated efforts to reveal the influence of acoustical criteria on the speech perception of students and their academic achievements. Research on the relationship of student speech perception with noise in the classrooms have been continuously undertaken. Bronzaft discovered that rail track noise negatively affects the reading ability of students [1]. Lukas demonstrated that a noisy environment of classrooms exerts definite influence on academic achievements. [2]. Houtgast determined that the intelligibility scores are found to deteriorate at noise levels exceeding a critical value of 15 dB with regard to a teacher's long-term speech level [3]. Shield found that test scores were also affected by internal classroom noise, with background levels being significantly related to test results. Negative relationships between performance and noise levels were maintained when the data were corrected for socio-economic factors relating to social deprivation, language, and special educational needs [4]. In Germany, it was found that learning achievement was better in a quiet environment after monitoring acoustic parameters measured in elementary schools [5].

Meanwhile, many research studies concluded that acoustic criteria such as reverberation time are also closely related to academic achievement. Nabelek reported that speech intelligibility test scores were higher in the babble environment with impulsive noise when reverberation time was short [6].

Recently, research was published that states it is necessary to consider not only learning achievement but also ease of listening. In this research, it was shown that reverberation time has a high impact on listening effort (LE) [7]. In addition, many studies have been conducted on various acoustical parameters in classrooms.

Bradley suggested three parameters: 50 ms early/late sound ratio, useful/detrimental ratios, and combinations of the reverberation time and background noise level as the more influential factors on speech intelligibility [8]. Studies on diverse binaural classroom acoustics parameters have been continuously carried out, which may affect speech intelligibility and student achievement [9,10].

To provide an appropriate acoustical environment for learning to students, it is necessary to create an acoustical performance standard for classrooms and a guideline for designing classrooms. Currently, in the United States and the United Kingdom, the acoustic performance standards and guideline of classrooms based on reverberation time (RT) and background noise (BN) are established [11,12]. These standards and guidelines are strictly applied to the construction and reconstruction of school buildings. Internationally, the standard of background noise level of classrooms was established at 30–35 dBA in most countries. However, standards for other acoustical parameters of each countries show significant differences due to languages. Especially in the case of reverberation time, the standards in Chile, Norway, Denmark, etc. are established at 0.6 s. Meanwhile, standards for Germany, France, Italy, China, and Malaysia have been established at 0.8 s. In other countries, RT standards have been distributed from 0.4 to 1.2 s depending on the classroom size and the student age. Conversely, certain countries do not have reverberation time standards, such as South Africa and India [13–16].

Regarding STI, very few countries have established standards. In certain countries, including the UK, Chile, and Italy, the STI standard is used restrictively for special usage of classrooms. This indicates that school classrooms are required to have a consistently quiet environment in all countries, but reverberation times are operated differently depending on the language and building environment of each country. Therefore, the present study aims to focus on establishing a reverberation time standard suitable for Korean classrooms.

Meanwhile, various studies have been undertaken on the acoustical environment of classrooms in Korea. Investigations of both performance of room acoustics and sound insulation were accomplished in many school classrooms that were built from 1984 to present, using different construction methods. As a result, it was found that the average reverberation time of Korean classrooms is below 0.8 s and many old classrooms have more than 1.0 s [17,18]. Besides traffic noise from outside, it was found that various noise sources inside rooms, including air-conditioner, also significantly influence speech perception of students [19,20]. Haan & Park investigated the inter-aural level differences that are caused by uneven distribution of room absorption inside the classroom, and how it may adversely affect speech intelligibility of students [21]. Based on the research, a guideline of designing classrooms with minimal inter-aural level differences is being created for better clear acoustic conditions [22].

In a space with similar acoustical conditions, there are different factors that affect speech intelligibility, depending on the language, such as English, Chinese, and Korean [23]. Therefore, it has been proposed that acoustical environment standards should be established that are appropriate for the language used when designing school classrooms. However, in Korea, there has not been research on the proper speech clarity for students in the classroom and sound performance standards have not been established. Therefore, it is difficult to control and manage appropriate acoustical performance when designing and building classrooms.

In Korea, schools are used by students of various ages from 6 to 18 years old comprising elementary, middle, and high schools. However, speech perception ability of the students changes with age. As a result of experiments in spaces with reverberation times of 0.47 s and 1.1 s, it was found that first graders were most affected but adults were hardly affected [24]. Especially for 7-year-old children, it was found that a significant decrease in comprehension occurred when the teacher's voice was low and the background noise was loud. However, children over 14 years old have similar speech recognition abilities as adults [25]. Therefore, it is necessary to establish the acoustical standard of the classrooms according to age.

The major goal of the present study is to suggest an appropriate reverberation time for classrooms suitable for the Korean language, especially for Korean middle and high school students who have adult-like listening abilities. For this purpose, the standard model of the Korean classroom was reproduced, and various reverberation conditions were created by changing the sound absorption using a computer simulation. Under these conditions, the speech intelligibility tests were undertaken by adults with normal hearing using auralized sound.

The entire experiment and speech intelligibility tests were conducted in 2013, prior to the COVID-19 pandemic. Therefore, the effects of facemasks and screens were not considered. According to a recent paper, it was reported that protections such as face masks affect acoustic transmission. It has also been reported that the transmission characteristics of voice are deformed, depending on the material and the protective area [26].

2. Previous Studies

Accurate standards for sound performance of classrooms suitable for listening are essential in order to provide students with uniform sound performance. In addition, acoustic performance standards and guidelines for architectural design and construction must be presented to achieve this performance. As mentioned earlier, the US and the UK have established sound standards and applied them to the construction and remodeling of classrooms.

The acoustic performance standards for the United States and the United Kingdom are classified into various characteristics, such as the purpose and the volume of the classroom and the age of the student in which each standard is presented. It also provides guidelines for the use of interior finishing materials as well as architectural planning methods to meet the acoustic performance targets presented in the standards for new construction and renovation of classrooms. These standards also include detailed descriptions of the sound insulation design for creating a quiet sound environment in classrooms. The acoustic performance standards used in the United States and the United Kingdom are shown in the Tables 1 and 2 below.

A previous study showed that Korean, English, and Chinese speech clarity can be different in the same space [23]. The effective factors for speech intelligibility may be different depending on the characteristics of each language. Therefore, appropriate acoustical standards should be established for each language when planning the classroom.

Table 1. The acoustic performance standard for the classroom in the US (unoccupied).

Classroom Size	BN (dBA/dBC)	RT (s)
under 283 m^3	35/55	0.6 s
283~566 m^3	35/55	0.7 s
above 566 m^3	40/60	-

Table 2. The acoustic performance standard for the classroom in the UK (unoccupied).

Classroom Type		BN (dBA)	RT (s)	STI
primary school		<35	<0.6	-
middle and high School		<35	<0.8	-
open-plan classroom		<40	<0.8	>0.60
lecture room	<50 people	<35	<0.8	-
	>50 people	<30	<1.0	-

In addition, a total of 14 classrooms of elementary, middle, and high schools in Cheong-ju were selected to measure the sound quality of Korean school classrooms. The measured acoustical parameters were background noise and reverberation time, and the results were compared with the acoustical performance standards of the US and the UK

Table 3 represents the information of the subject school classrooms, such as construction year, district classification, and architectural dimensions.

Table 3. Information about the subject schools and classrooms.

Classification		Construction Year	District Classification	Architectural Dimension of the Classroom				Grade of Subject Students
				Length (L)	Width (W)	Height (H)	Volume (V)	
Elementary school	E-R1	1972	Roadside area	7.9 m	8.0 m	2.6 m	164.3 m^3	grade 6
	E-G1	1981	General area	7.0 m	8.8 m	2.9 m	178.6 m^3	grade 2,6
	E-G2	2007	General area	7.4 m	8.4 m	2.6 m	161.6 m^3	grade 2,6
	E-R2	2008	Roadside area	7.7 m	8.2 m	2.6 m	164.2 m^3	grade 1,6
		Average		7.5 m	8.4 m	2.7 m	167.2 m^3	-
Middle school	M-G	1986	General area	7.2 m	8.6 m	2.8 m	173.4 m^3	grade 8
	M-R1	1993	Roadside area	7.3 m	8.9 m	2.8 m	181.9 m^3	grade 8
	M-R2	1995	Roadside area	7.3 m	8.8 m	2.6 m	167.0 m^3	grade 8
	M-R3	2007	Roadside area	7.3 m	8.2 m	2.6 m	155.6 m^3	grade 8
		Average		7.3 m	8.6 m	2.7 m	169.5 m^3	-
High school	H-G	1991	General area	7.5 m	9.0 m	2.7 m	182.3 m^3	grade 12
	H-R1	1974	Roadside area	7.5 m	9.0 m	2.9 m	195.8 m^3	grade 12
	H-R2	1977	Roadside area	7.5 m	8.5 m	3.0 m	191.4 m^3	grade 12
		Average		7.5 m	8.8 m	2.9 m	189.8 m^3	-

The name of school in the classification column represents the main information of the school. The first letter categorizes the subject school as elementary (E), middle (M), or high (H) school. The second letter indicates the district classification of each school. G represents the general residential area and R represents the roadside area.

All the acoustic parameters were measured based on ISO 3382-2. The measurements were undertaken in the unoccupied classroom during vacation. Measurements were performed during the daytime in 2012.

The locations of the sound receiving points were set up differently when measuring background noise and reverberation time. In the case of background noise measurement, there were no significant deviations by location. Thus, the background noise level was measured at the center of the classroom. However, reverberation times were measured at 9 points that were evenly distributed in the classroom. The height of the sound receiving point was installed at 1.2 m height from the floor. Figure 1 shows the location of the sound receiving points for measuring background noise level and reverberation time.

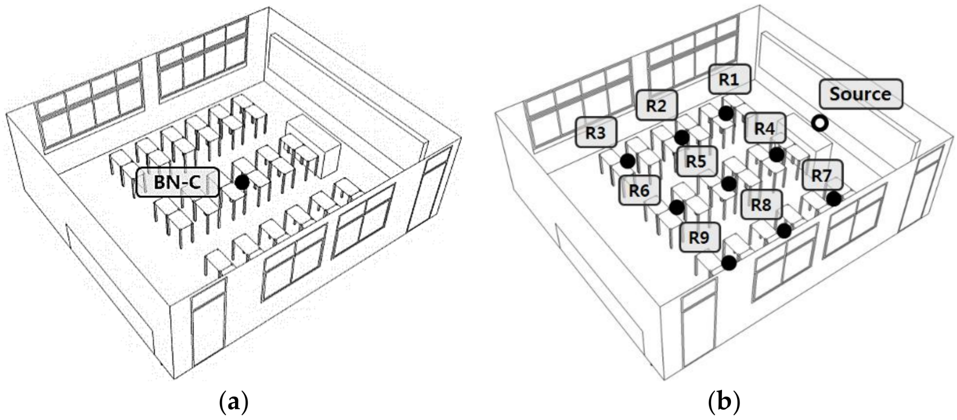


Figure 1. The location of sound sources and receiving points for measurements in the classroom. (**a**) Background noise level; (**b**) reverberation time, T_{30}.

Acoustic measurement results of background noise and reverberation time in Korean classrooms are shown in Figures 2 and 3 [18,19,22]. In Figure 2, gray bars represent the measurement results of background noise in schools in the general residential area while the black bar shows the background noise level of schools located in the roadside area.

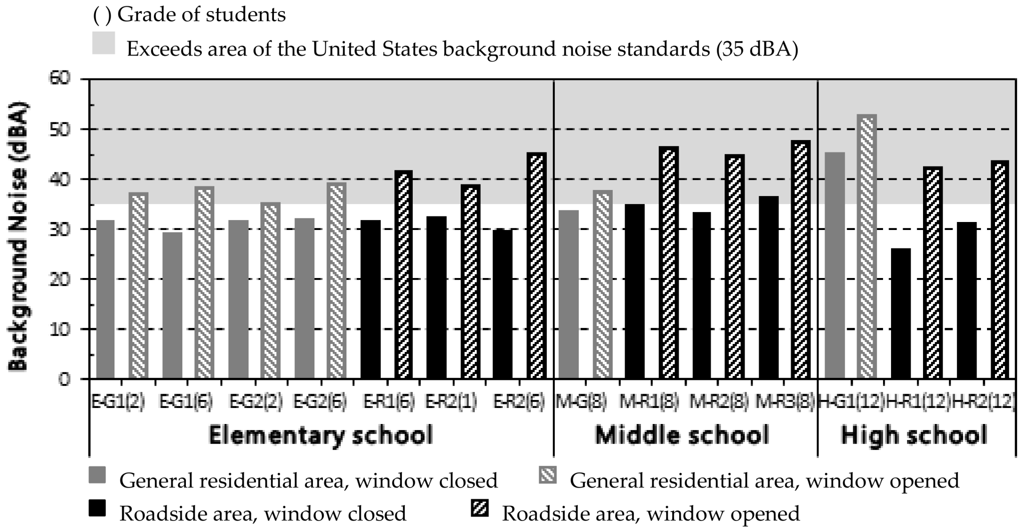
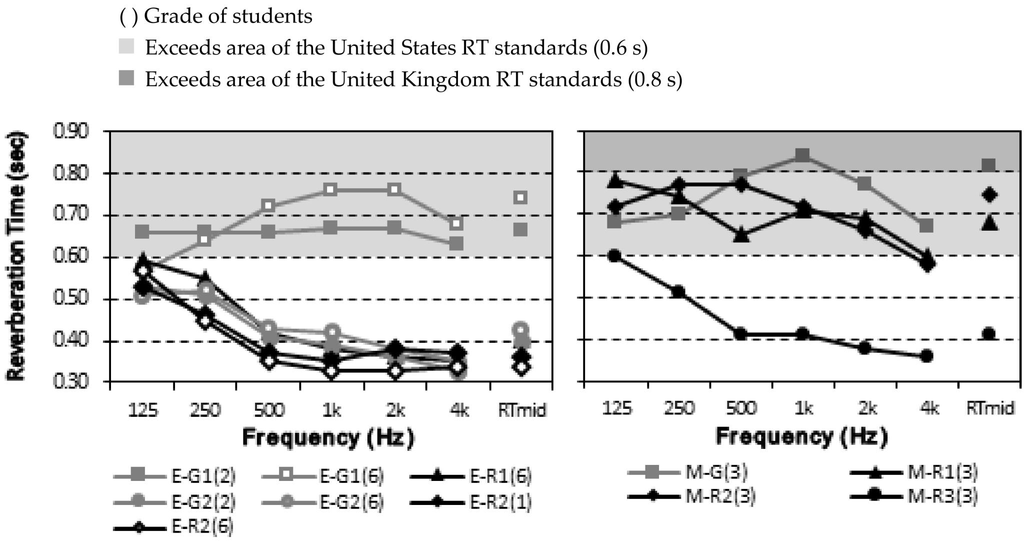


Figure 2. Measurement results of background noise levels in Korean classrooms (unoccupied).

Figure 2 represents the background noise levels of the unoccupied classroom. The solid bars show the results when windows are closed, and the slashed bars show the results when windows are opened.

Experiment results have shown that background noise levels exceed the US and UK standards of 35 dBA in schools located on the roadside. In particular, when the windows were opened, the background noise was found to exceed the standard in all schools. Therefore, it can be inferred that external noise interferes with speech perception of the student while the windows are opened. In addition, it was found that the background noise of elementary schools was lower than middle and high schools. This may result from the speed limitation of under 30 km/h on the roads adjacent to the elementary schools. From the results, it was determined that middle and high schools demand different noise regulations.

Figure 3 shows the average reverberation times of nine receiving points in elementary and middle school classrooms. The reverberation time was found to exceed the US standard of 0.6 s in several elementary and middle schools.



(**a**) Elementary school (**b**) Middle school

Figure 3. Measurement results of reverberation time in Korean classrooms (unoccupied).

The reverberation time of the classrooms was approximately 0.4 s in three elementary schools, which satisfies the standard of the United States. However, the E-G1 school had a long RT_{mid} of 0.67–0.74 s due to aged facilities. Conversely, it was found that the reverberation times exceeded the standard of the United States in the three middle school classrooms. It may be inferred that the sound absorption amount was less than that of elementary school classrooms. Generally, in elementary classrooms, there are many crafts and pictures posted on the walls.

According to previous studies, it can be suggested that acoustical standards should be established differently, depending on the students, since conditions are different between elementary schools and middle and high schools such as speech perception ability, driving speed regulations of adjacent roads, and characteristics of classroom use.

3. Research Method

In order to establish the acoustical standard of Korean classrooms, it is significant to investigate the appropriate acoustical condition for learning using Korean. The speech intelligibility test was required to find critical points in various acoustical conditions.

In this study, the reverberation times of a Korean standard classroom were varied by indoor sound absorption using computer simulations. PBW sound sources were recorded in an anechoic chamber and convoluted with binaural impulse responses. They were used as auralized sound sources. Lastly, speech intelligibility tests were performed to analyze the speech intelligibility score of students in diverse reverberation conditions.

All the experiments using people were approved by the Korean regulations and IRB (institutional review board) before stating the present study.

3.1. Standard Model of the Korean Classroom

In Korea, standard design documents have been used for a long time, which can create classrooms with the same conditions, including size and interior materials. Thus, the architectural dimensions of classrooms could be standardized. The standard design documents have been used as a design and planning guideline for all the schools in Korea.

This document was established for the standardization of educational facilities, improvement of constructional efficiency, and simplification of administrative procedures in Korea. The standard design documents standardized interior materials and the size of various facilities in school such as general classroom, special classroom, corridor, toilet, gymnasium, etc. The documents were enacted in 1962 by the Ministry of Education and

Culture of the Republic of Korea and used until 1997. However, after the standard design document was abolished, the architectural dimensions of classrooms did not change significantly. The standard classroom of Korea is shown in Table 3. In the present study, the model of the Korean classroom was produced using standard classrooms of Korea.

The three-dimensional model of the Korean standard classroom was created to identify the architectural characteristics and to implement the different acoustical condition. The standard model was created based on the average value of investigated schools including 17 middle schools out of 34 and 7 high schools out of 29 schools in Cheongju city in Korea.

The standard model of the Korean classroom has a rectangular shape with a width of 7.3 m, length of 8.5 m, and height of 2.7 m. The floor area is 62.1 m^2 with a volume of 172.8 m^3. This classroom can accommodate up to 36 students. The shape and architectural dimension of the Korean standard model is illustrated in Figure 4 [16].

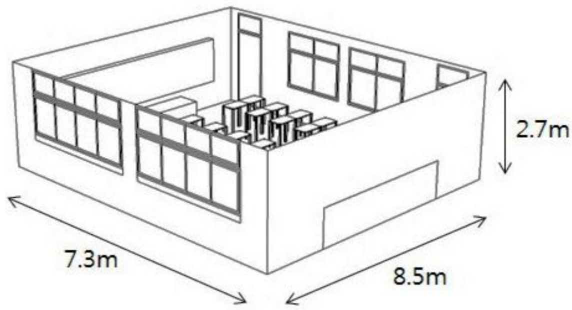


Figure 4. Standard model of Korean classrooms.

3.2. Differences of Reverberant Condition for the Speech Intelligibility Test

On the basis of the standard model, auralized sound sources were created with five different conditions of reverberation times using different absorbing coefficients of materials. Table 4 provides information about the indoor finishing materials and the sound absorbing coefficient of real materials that were used in computer simulations.

According to a survey on the acoustical performance of classrooms conducted on middle and high schools in Korea, the average reverberation time was 0.75 s [19]. In this study, the five steps of reverberation conditions were selected based on 0.75 s to obtain students' responses in various acoustical environments.

In the simulation, the indoor finishing materials were changed to create five different conditions of reverberation time. The range of reverberation time (RT) is displayed in Figure 5.

Table 4. Sound absorbing coefficient (NRC) for computer simulation.

Location	Interior Finishing Material	NRC	Remark
floor	smooth concrete	0.015	
window	glass plate with metal frame	0.038	
door	wooden door	0.085	
black board	black board	0.083	unchanged real material applied to every simulation
rostrum	wooden panel	0.083	
desk	wooden desk	0.075	
locker	wooden panel	0.083	

Table 4. *Cont.*

Location	Interior Finishing Material		NRC	Remark
wall & ceiling	min. RT	wall: painted concrete	0.015	real materials were applied to make the state of minimum and maximum RT
		ceiling: sound absorbing board	0.518	
	max. RT	wall: painted concrete	0.015	
		ceiling: wooden panel	0.083	
	sound absorbing coefficient: 0%		0.000	same sound absorption coefficient for all frequency bands applied for RT control
	sound absorbing coefficient: 5%		0.050	
	sound absorbing coefficient: 10%		0.100	
	sound absorbing coefficient: 15%		0.150	
	sound absorbing coefficient: 20%		0.200	
	sound absorbing coefficient: 25%		0.250	
	sound absorbing coefficient: 30%		0.300	
	sound absorbing coefficient: 35%		0.350	
	sound absorbing coefficient: 40%		0.400	

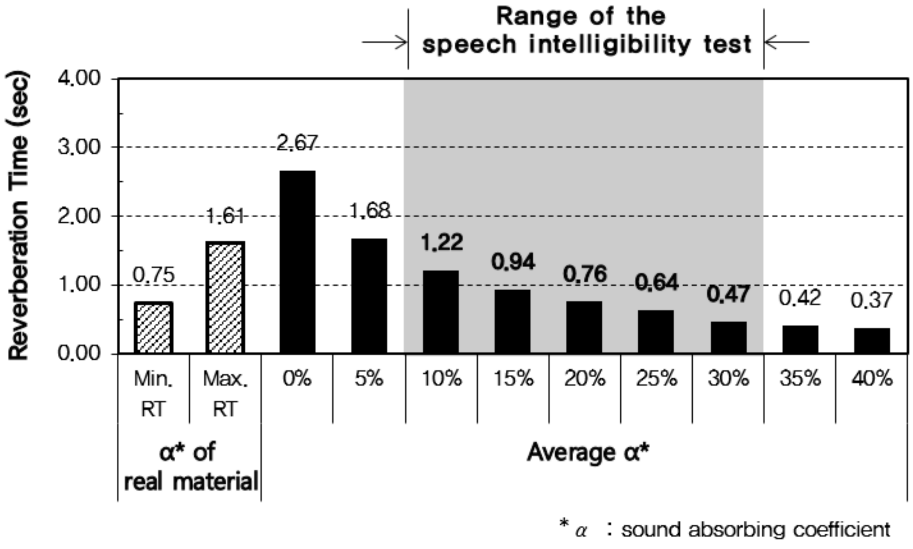


Figure 5. Differences of acoustical parameters in the various conditions of Korean classrooms.

The vertical axis of Figure 5 represents the average reverberation time (RT_{mid}) of mid-frequency that affects speech recognition most. The grey bars describe the maximum difference of reverberation times of simulated Korean standard classrooms. When all the possible sound absorption materials could be practically applied, RT_{mid} was 0.75 s while 1.61 s could be obtained when minimum sound absorption materials were used. The black bars present the deviation of the reverberation times, which were changed by various average sound absorbing coefficients of rooms. The same sound absorption coefficient (α) was applied to all frequency bands during the simulation.

As a result, the RT of the Korean standard classroom in real state was 0.75 to 1.61 s and STI was 0.68 to 0.47. In addition, the range of RT in simulations varied from 0.37 to 2.67 s in the virtual state when the average sound absorbing coefficients were applied to sidewalls and the ceiling, from 0% to 40%. Therefore, RT of auralized sounds for speech intelligibility tests were chosen between 0.47 s and 1.22 s, which could identify the appropriate range of the listening environment.

3.3. Auralization

The speech intelligibility tests were conducted using auralization techniques. Producing the auralized sound was started by inputting the sound absorption coefficient to each part of the standard classroom in the virtual sound field. In the next step, the signal was generated through the sound source using a directivity pattern. The sound source was created by Odeon using a human voice directivity pattern. In this process, binaural room impulse responses of the virtual standard classroom can be obtained. The calculated binaural synthesis and room acoustic performance of the standard classroom were convolved with a head related transfer function (HRTF). As a last step, auralized sound could be produce by convolving these acoustical information with the Korean PB words, which was recorded in an anechoic chamber.

Furthermore, the length and play order were edited using Adobe Audition. Auralized sound was provided to the listener through headphones. Using this method, the subject can experience the same acoustics in a real classroom. In this study, the auralized sound was produced using the sound from a receiving point located in the center of the classroom. Table 5 lists the equipment used to produce the auralized sounds. The product process of auralization is described in Figure 6.

Table 5. The equipment list for producing auralized sound.

Classification		Content
	anechoic sound source	PB word list in Korean
Recording	microphone (polar pattern)	Earthwork SR78
	digital stereo audio recorder	TASCAM HD-P2
Convolution	room acoustic simulation software	Odeon combined v.12
Editing source	sound editing program	Adobe Audition cs3

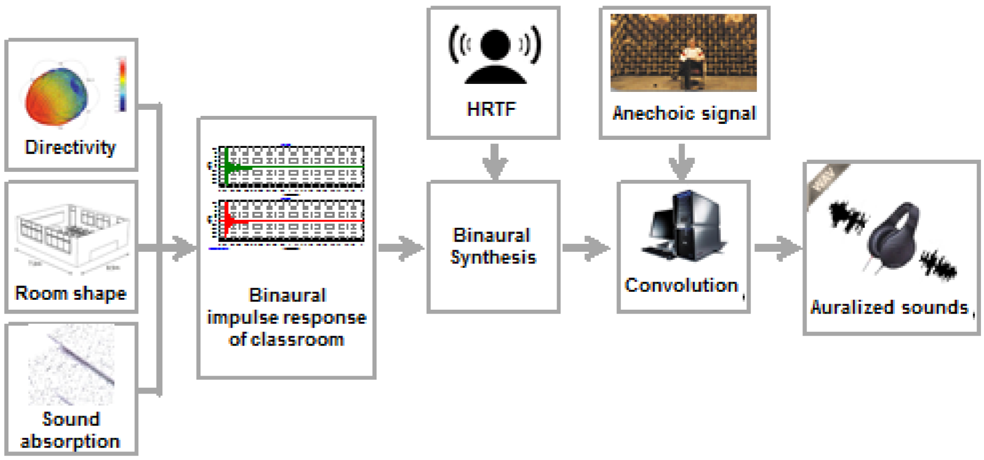


Figure 6. Product process of auralized materials.

3.4. Speech Intelligibility Test

Every experiment was conducted according to the procedures specified in ASA S3.2, and the test results were evaluated according to ISO 9921 [27,28].

There are various methods for speech intelligibility test in ISO9921, but the SRT, CVC, and PBW methods are mainly explained. The SRT method is a test method that uses simple sentences that contain numbers. The SRT method normally has a high speech intelligibility score due to the characteristics of the method. Therefore, it is used to evaluate speech intelligibility with poor conditions of the listening environment.

The CVC_{EQB} method uses a voice list with an equally balanced phoneme distribution as a word composed of consonant-vowel-consonant. The advantage of CVC_{EQB} is that the phoneme error rate of each phoneme is determined with equal accuracy and that a balanced nonsensical confusion matrix is obtained.

The PBW method to evaluate the accuracy of speech perception using a word list consisted of 50 single syllables. The PBW method is easy to evaluate speech intelligibility because the influence of the signal-to-noise ratio is large. It is the longest-used method of speech intelligibility tests and its accuracy and efficiency was certified by ISO9921. Moreover, PBW is the most commonly used test method, and it allows direct comparison with many other research results. Therefore, in this study, the speech intelligibility test was undertaken using the PBW method.

During the auralized test, the subjects were required to listen to the words shown in Table 6 through their headphones for two seconds and write them down for three seconds. It took about five minutes to conduct one test, and to prevent decreased concentration due to hearing tiredness, about five minutes of rest were given after each test.

Table 6. The example of the word lists for the speech intelligibility test [29].

락	쇠	씨	르	승	꼬	하	오	쭉	엄	겨	깨	질	멀	똥	깜	둑	상	님	절	연	푼	식	록	머
쌍	빈	꿀	등	룽	담	란	뜸	레	꿈	틀	임	데	젓	짝	울	토	밥	께	과	름	분	집	찍	슴

The output level of auralized sound sources was 50 dBA heard at headphone. Assuming that the background noise level of classroom is approximately 35 dBA, output level of 50 dBA could be perceptible level for subjects because the minimum SNR is 15 dB for speech intelligibility.

Figure 7 compares three types of speech intelligibility tests scores with STI, which is suggested in ISO 9921. This figure was used to evaluate the result of speech intelligibility test. The vertical axis of the graph represents the correct answer rate of each test method. The horizontal axis shows the speech perception of human with the STI value in five stages.

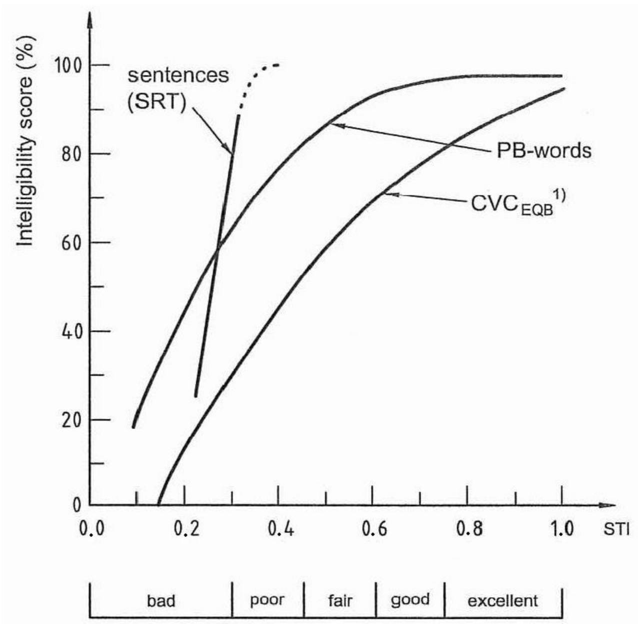


Figure 7. Comparison of intelligibility score and STI using three types of speech intelligibility test methods.

According to the analysis, the evaluation results of speech clarity under the PBW method must be approximately 80 points or more to satisfy the minimum limit of speech transmission performance for the classroom.

Closed-type headphones were used to transmit the auralized sound to the subject. In all speech intelligibility tests, the auralized sound was simultaneously transmitted to eight subjects simultaneously through the 8-channel headphone amplifier. Table 7 and Figure 8 show the list of equipment and the device configuration diagram used for the speech intelligibility test.

Table 7. Equipment list used for the speech intelligibility test.

Device	Manufacturer and Model	Quantity
headphone	Senheiser HD 280	8
headphone amplifier	Behringer powerplay pro-8 (8 ch)	1
sound player	Samsung notebook	1

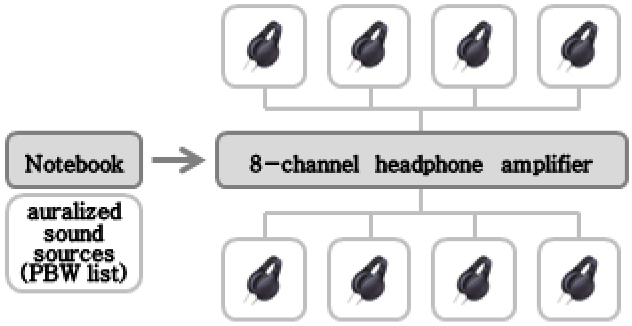


Figure 8. Equipment configuration diagram for the speech intelligibility test.

4. Establishment of the Reverberation Time Standard for Korean Classrooms

4.1. Result of Speech Intelligibility Test

Using auralized sound, speech intelligibility tests were conducted under various reverberation conditions. The reverberation time was produced in five steps from 0.4 s to 1.2 s with 0.2 s intervals. Speech intelligibility tests were conducted nine times in 2013. The subject group consisted of 72 university students aged 20 to 27 with normal hearing. Speech intelligibility tests were conducted in adults versus middle and high school students because the hearing ability of students over the age of 14 is similar to adults [25].

All tests were conducted in a room isolated from external noises. The background noise of the room was approximately 27 to 32 dBA. Figure 9 represents the process and duration of the listening test.

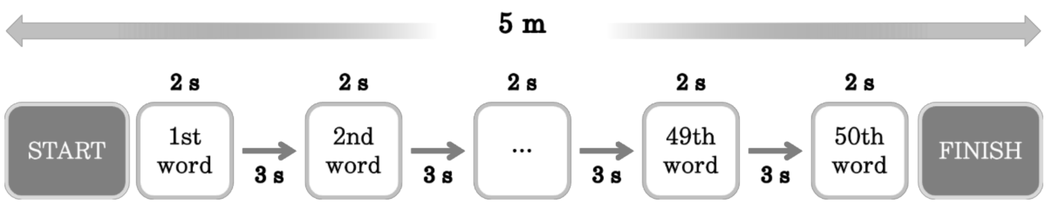


Figure 9. Process and duration of the speech intelligibility test.

The subjects listened to auralized sounds for 2 s and dictated the syllables for 3 s. The duration of one test was about 5 min, and the total test time including the break was about 30 min. To avoid hearing exhaustion, the subjects rested for 1 to 5 min after every test. Moreover, to prevent familiarization about reverberation, the auralization materials were provided randomly as shown in Table 8.

Table 8. Test order and reverberation time for speech intelligibility test.

Test Order	RT (s)
1	1.0 s
2	0.6 s
3	0.4 s
4	0.8 s
5	1.2 s

Table 9 and Figure 10 show the speech intelligibility test scores with the sound absorption input and average reverberation time (RT_{mid}) data. The vertical bars in Figure 11 indicate the minimum and maximum scores in each test.

Table 9. Speech intelligibility score in the various RT conditions of the classroom.

Average of α * (%) **RT (s)**		30% 0.4	25% 0.6	20% 0.8	15% 1.0	10% 1.2
Score	Average	**82.7**	**82.3**	**80.4**	**70.0**	**70.2**
	Maximum	92.0	90.0	90.0	92.0	90.0
	Minimum	68.0	62.0	62.0	50.0	42.0

* α: sound absorbing coefficient.

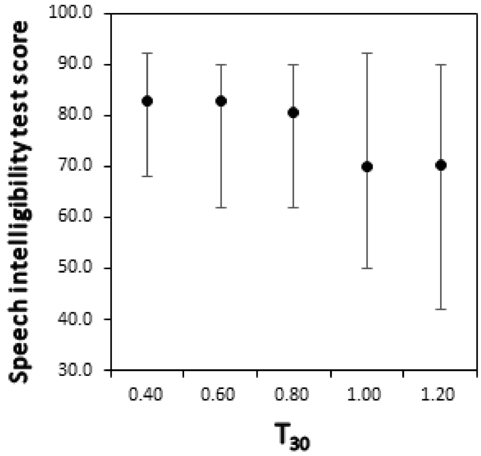


Figure 10. Comparison of speech intelligibility scores with RT.

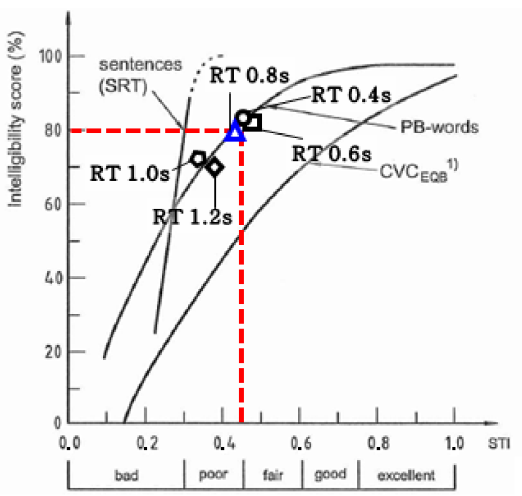


Figure 11. Comparison of speech intelligibility score and STI with perception of listener.

The results denote that the scores satisfy the minimum standard of 80 points for proper voice transmission performance when the RT was 0.8 s or less. Conversely, when the RT exceeded 0.8 s, the score appeared to be around 70 points, indicating that the minimum criteria was not satisfied. In particular, if the reverberation time was longer than 1.0 s, the maximum score was approximately 90 points, similar to the result when the reverberation time was short. However, the deviation between the subjects was sufficiently large that it was considered difficult to transmit the speech information of teachers to all students.

Figure 11 shows the speech intelligibility scores plotted on the graph of Figure 7. In general, the minimum level of STI was in the range of "fair", which can be defined as 0.45 to 0.60. Therefore, for the PBW test, scores larger than 80% can be recognized as proper speech perception. As a result, the scores of the speech intelligibility test were satisfied when the RT of a standard classroom was below 0.8 s. Therefore, to ensure the appropriate speech intelligibility, the RT should be below 0.8 s.

4.2. Acoustical Standard of the Korean Classroom

Consequentially, the present study suggests the standard of Korean classrooms for appropriate speech transmission as shown in Table 10. The standard is for middle and high school students with normal hearing who speak Korean. Since speech transmission performance can be different by language in the same listening environment, this standard should be applied only to the classrooms for Korean students. Also, this standard cannot be applied to special classrooms for learning music, painting, and physical activities.

Table 10. Acoustical standard of Korean classrooms (example).

Background Noise Level *	Reverberation Time (RTmid) **
below 35 dBA	below 0.8 s

* Average of SPL in 125–4 kHz. ** Average of reverberation time in 500–1 kHz.

This standard has its own characteristic unlike other international standard of the US and UK. Table 11 compares each standard of the US, UK, and the results of the present study. In the US, the standard has no limits for age to apply. Moreover, the limit of RT is shorter (0.6 s) but the volume standard of classrooms is bigger (280 m^3) than others. Conversely, the UK standard has limits of age, and the RT is similar to the results of this study.

Table 11. Comparison of acoustical standard in various country.

Country	Grade	Volume	Acoustical Parameter	
			BN *	RT
Korea (example)	middle and high school	below 220 m^3	below 35 dBA	below 0.8 s
US *	all school	below 283 m^3	below 35 dBA	below 0.6 s
UK **	middle and high school	no limitation	below 35 dBA	below 0.8 s

* ASA S12.60: acoustical performance standard, design requirements, and guidelines for schools. ** Building Bulletin 93: Acoustic Design of Schools a Design Guide.

These standards consist of the characteristics of their languages and relate to the education system and construction type. Therefore, for a new school, these standards should be considered to provide an appropriate environment for learning.

5. Conclusions and Discussion

The present study investigates the subjective speech intelligibilities in various conditions, changing the reverberation time with indoor sound absorptions. The present study was conducted to find an appropriate reverberation time standard for middle and high school classrooms in Korea. As a result, the acoustical standard for Korean classrooms was suggested for middle and high school students.

The conclusions derived from the present study can be summarized as follows:

(1) The target acoustical parameter is reverberation time and background noise;

(2) Background noise level should not exceed 35 dBA to perceive the minimum speech level of teachers;
(3) RT should be shorter than 0.8 s to transmit the information for learning from teachers in a normal classroom.

The present study has limitations in age of students; thus, in order to make general acoustical standards, more research should be conducted as subsequent studies, which can include elderly people, young children, hearing impaired individuals, autistic students, and others. Investigations of Korean acoustic standards for children under 9 and elderly people over 65 have been undertaken since 2020 as a different project. Furthermore, a study on the acoustic environment for speakers is necessary since speakers' vocalization tiredness can occur in a classroom with short reverberation time.

In order to supplement the findings, additional experiments are needed to be undertaken in the near future. These standards should be applied to classrooms within the designated volume.

Thus, the follow-up research for these limitations should be conducted in the future and the architectural guidelines should be suggested to satisfy the standard when the classroom is designed or constructed.

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