THE JOURNAL OF THE ACOUSTICAL SOCIETY OF KOREA Vol.28, No.2E 2009 6. pp. 60~65

Enhancement of Sound Clarity of Classrooms Using Sound Diffusers and Panel Absorbers

Sang-Bong Shin*, Chan-Hoon Haan*
*Dept. of Architectural Engineering, Chungbuk National University
(Received June 10 2009; accepted June 12 2009)

Abstract

The present study aims to investigate the effects of sound diffusers and absorbers on the sound clarity in classrooms. In order to do this, computer simulations were carried out to find the effective area of treatment which could enhance the sound clarity in the room. Acoustic measurements were undertaken in a lecture room with several conditions changing the surface of walls and ceilings with diffusers and absorbers. Diffusion and absorption treatments were applied to the side walls, rear wall and the ceiling of the classroom. SPL, RT, D50, RASTI were measured at 9 measurement points with one sound source and MLS was used as the sound source signal. The results show that higher sound clarity was obtained when diffusers were applied to rear walls and ceiling rather than side walls. Also, it was confirmed that absorption increased sound clarity more effectively with smaller amount in comparison with diffusers. It was also concluded that the effects of sound diffusers and absorbers on the sound clarity could be obtained distinctly at the rear area of the classroom.

Keywords: *Classroom acoustics, Sound clarity, Acoustic measurements, Sound definition, Sound diffusers, Sound absorbers, Air cavity*

I. Introduction

Acoustic environment in classrooms is critical in the performance of education in schools. Conventionally, voice communication has been the dominant pedagogy for teachers to teach students. The importance of the audio-visual facilities in classrooms is getting increased as more aural information is transferred for the educational purpose. Thanks to the advanced multi-media devices audio-visual facilities has also become very common. Electro-acoustical treatment were tried to enhance the speech intelligibility of classrooms. [1][2]

The acoustical condition of classrooms becomes also important matter. Acoustic modelings were carried out to investigate the speech metrics [3] and sppech criteria [4] of classrooms. And acoustic experiments were accomplished to find physical attributes affecting acoustics of classrooms. [5] However, the sound clarity of classrooms is to be poor since the room acoustic criteria have not been considered in most schools except those built recently.

The previous studies investigated the effects of sound diffusers and absorbers on the sound clarity in classrooms [6][7]. Especially, the knowledge on the specific area and the amount of absorptive or diffusive treatments is to be found which could effectively increase the sound clarity in classrooms. Ultimately, we intended to find the effective surface and the amount of acoustical treatments in order to increase the sound clarity in classrooms.

Accordingly, this study has conducted the room acoustic experiment with a set of sound diffusers and sound absorbers in order to improve the acoustic environment and the sound intelligibility of lecture

Corresponding author: Chan-Hoon Haan (chhaan@chungbuk.ac.kr)
410, Sungbong-ro, eung-duk-ku, Cheongju, 361-763, Korea

rooms in colleges. Varying the size of air cavity, the experimental results of sound definition and RASTI have been analyzed. The result shows the acoustic environment has low quality so that it interferes with voice communication, and it turns out even a minor alteration of finish materials could improve the intelligibility of room effectively.

In order to carry out the present study, several works are need to be undertaken gradually as follows;

1) Pilot survey of acoustic performances using computer modeling ; preliminary study was performed using real scale 3-D model of a room with various finishing materials. The effects of varying materials and the location of absorption on the acoustics of a classroom were investigated through computer simulations.
2) On-site acoustic experiments ; acoustic measurements were carried out in an existing university classroom varying finishing materials according to the results of the preliminary study. As a second experiment, depth of air cavity were varied in order to investigate the correlation of cavity depth with the sound clarity of the classroom.

II. Acoustic Measurements

Acoustic parameters of sound clarity were measured using an ordinary empty rectangular classroom which has dimensions as listed in Table 1. Table 2 shows the sound absorption data of finishing materials of an ordinary classroom used for computer modeling.

The classroom used is a typical type of the university classroom which accommodates around 80 peoples. Most of wall material is cement blocks with painted mortar and the floor is covered by polished stone. The acoustic textiles are installed on ceiling with 150 mm air cavity under the concrete slab. The plan and interior sections of the classroom are plotted in fig. 2.

Acoustic measurements were undertaken in the classroom with several conditions changing the indoor surface of walls and ceilings with diffusers and absorbers. As sound diffusers, QRD734, Omniffusors and Hemiffusers were used on the walls and ceiling. As an additive absorptive material, Tactum panel was used to rear wall in order to find the difference of effectiveness comparing with the diffusive panels. Table 3 shows the contents of the experiments undertaken in the classroom. The abbreviated name of each measurement was listed at the far-right column. Coefficients of diffusion and ab-

Table 1. Architectural measures of the classroom.

Dimensions	Contents
Length (L)	10.92 m
Width (W)	7.75 m
Height (H)	2.90 m
Room volume (V)	212.5 m^3
Floor area (F)	82.5 m^2
Number of seats (N)	80 seats

Table 2. Sound absorption data of finishing materials used for computer modeling.

Material \ Hz		125	250	500	1K	2K	4K
wall	blackboard	0.24	0.20	0.20	0.18	0.18	0.21
	windows	0.35	0.25	0.18	0.12	0.07	0.04
	painted mortar	0.01	0.01	0.02	0.02	0.02	0.03
floor		0.01	0.01	0.01	0.02	0.02	0.02
table and chair without students		0.02	0.04	0.06	0.06	0.06	0.06
student seated on chair		0.20	0.30	0.40	0.40	0.40	0.40
ceiling		0.22	0.32	0.15	0.14	0.08	0.07

Table 3. Contents of the acoustic experiments.

No.	Area	Diffusers & Absorbers		Measurement name
1	current condition		-	CC
2	side wall	diffuser	QRD734	SW
3	rear wall	diffuser	Omniffusor	RW
4	ceiling	diffuser	Hemiffusor	C
5	side wall + ceiling	diffuser	QRD734 + Hemiffusor	SW+C
6	rear wall + ceiling	diffuser	Omniffusor + Hemiffusor	RW+C
7	rear wall	absorber	Tactum Panel + Fabric	RWT
8	rear wall	absorber	Air cavity 20 mm + Aluminium Foam	RWA 20
9	rear wall	absorber	Air cavity 70 mm + Aluminium Foam	RWA 70

Table 4. Coefficients of diffusion and absorption of the diffusers and absorber.

Material	Hz	125	250	500	1K	2K	4K
diffusion coefficient	QRD 734	0.71	0.73	0.88	0.80	0.69	0.56
	Omnifisor	0.80	0.72	0.65	0.70	0.67	0.66
	Hemiffusor	0.80	0.72	0.68	0.67	0.71	0.72
absorption coefficient	QRD 734	0.23	0.24	0.35	0.23	0.20	0.20
	Omnifisor	0.12	0.10	0.14	0.22	0.06	0.12
	Hemiffusor	0.12	0.10	0.14	0.22	0.06	0.12
	Tactum	0.06	0.13	0.24	0.45	0.82	0.64

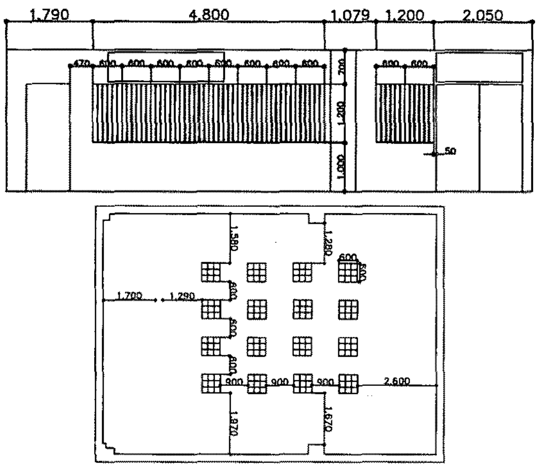
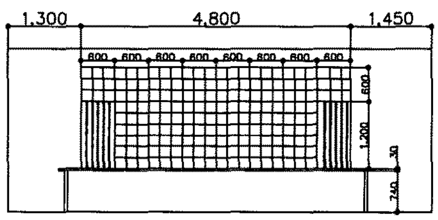
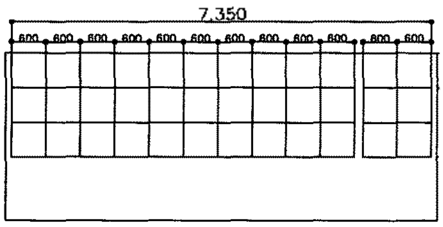


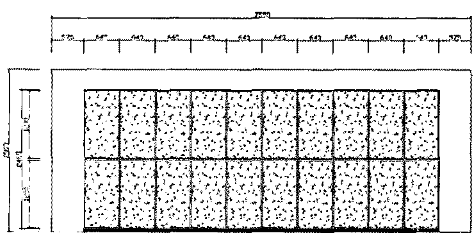
Fig. 1. Diffusive panels on the side wall and the ceiling.



(a) Omniffusor



(b) Tactum Panel + Fabric



(c) Aluminium Foam with Air cavity

Fig. 2. Diffusive panels and absorptive panels on the rear wall.

sorption of the diffusers and absorberused in the study are listed in Table 4.

Figures 1 to 2 illustrate the drawings of the side wall and ceiling of the classroom respectively which show the attachments of the diffusers in their area. And Fig. 2 also shows the rear wall of the classroom with different finishing conditions.

Acoustic parameters including SPL, RT, D50, RASTI which relate with the sound intelligibility were measured at the 9 measurement points with same sound power level of sound source. The distance among measurement points is 2.5−3.0 m away from each other. In each measurement, an omni−directional speaker was used as the sound source in classrooms. And MLS signal was used as the sound source signal. In each measurement, 80 dB of sound energy was radiated and the signal was taken by microphones which were set at the height of 1.1 m position from the floor. The measurements were carried out during the night and the background noise level was 22.6 dB(A) at 500 Hz. All the measurement procedures were carried out following the ISO standards.

Figure 3 shows the 9 measurement positions in the classroom. Figure 4 also shows the interior pictures of the classroom with acoustic diffusers installed. Acoustic measurement set−up for room acoustical

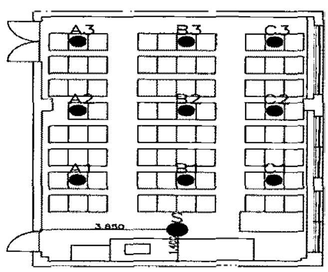


Fig. 3. Measurement positions in the classroom.

Fig. 4. Measurement positions and interior pictures of the classroom.

parameters is illustrated in Figure 5. Sound pressure levels were measured using B&K 2260 and other acoustic parameters were analyzed using ETANY ASA-2 audio sound analyzer.

III. Results of Acoustic Measurements

3.1. Sound Pressure Level (SPL).

SPL was measured at each point with 1 octave band and sound levels were analyzed according to the measurements with different diffusers and absorbers. Figure 5 displays the sound levels of each measurement as the function of frequencies.

In current condition, highest average sound level of 65.3 dB was measured when no diffusers and absorption were applied to the classroom. It is because there are rare absorptive materials in the current classroom. As shown in Fig. 5 similar sound levels were measured in each acoustic treatment within the deviation of 1.0 dB. This means that diffusive and absorptive treatments in classroom do not affect the sound levels remarkably.

3.2. Reverberation Time (RT)

Reverberation times of the classroom were measured with different set-up of diffusers and absorber. The average RT in empty states of the classroom is 1.78 sec. (1.45 sec in occupied state) This implies that the acoustics of the current classroom is not

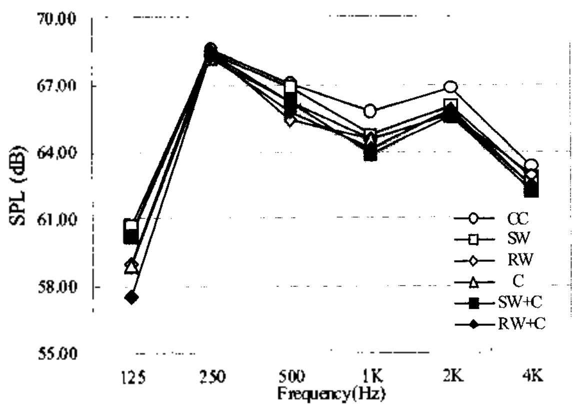


Fig. 5. Comparison of SPL of each measurement.

suitable for the speech communication. As predicted, the RT at the measurement with absorptive panels on rear wall was smallest 1.28 sec. Comparing the measurements with diffusers only, it was found that approximate of 0.15-0.25 sec of reverberation times was shorter than other measurements when diffusers are applied to both rear wall and ceiling. The maximum difference of 0.34sec was measured at the 250 Hz where highest sound levels were measured.

3.3. Sound Definition (D50)

The average sound definitions (D50) of each measurement are plotted as the function of frequency in Fig. 7. It shows that the average D50 value of the current state is lowest (0.33) among measurements at the most frequencies and average D50 value is highest (0.43) when absorptive panels were applied to rear wallof the classroom. Comparing the D50 values of each measurement with diffusers only, it is realized that the ceiling is more effective

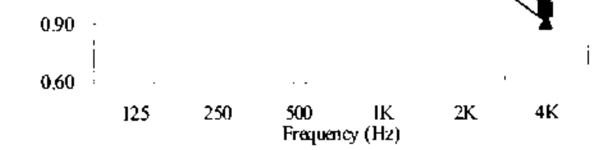


Fig. 6. Comparison of RT of each measurement.

Table 5. Reverberation times of each measurement.

Measurement	Frequency (Hz)						RT_mid
	125	250	500	1K	2K	4K	
CC	1.61	1.67	1.60	1.95	1.69	1.18	1.78
SW	1.64	1.51	1.50	1.76	1.60	1.06	1.63
RW	1.51	1.46	1.47	1.54	1.44	0.99	1.51
C	1.77	1.63	1.38	1.77	1.50	1.00	1.58
SW + C	1.38	1.39	1.40	1.61	1.49	0.98	1.50
RW + C	1.39	1.34	1.38	1.54	1.44	1.00	1.46
RWA	1.83	1.44	1.39	1.17	1.22	0.91	1.28

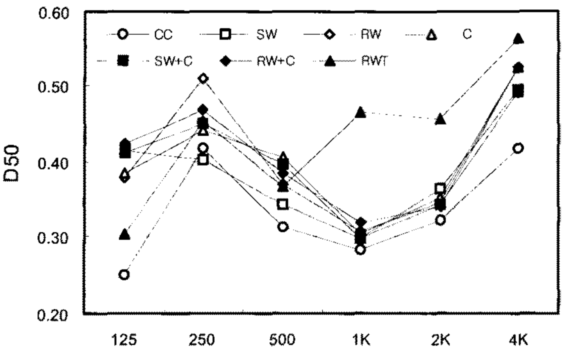


Fig. 7. Comparison of average D50 of each measurement.

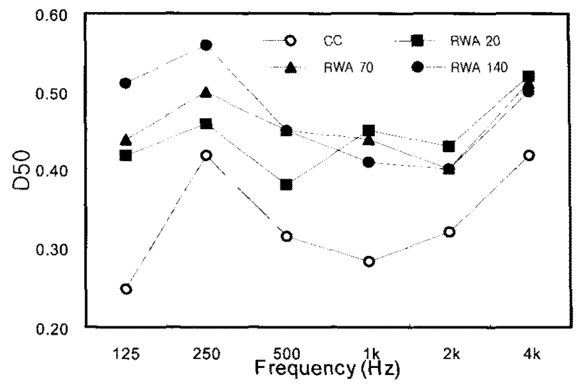


Fig. 8. Comparison of D50 depending on the depth of air cavity.

Table 6. Sound definition (D50) of each measurement at the rear area of the classroom.

Measurement	Frequency (Hz)						AVG
	125	250	500	1K	2K	4K	
CC	0.13	0.29	0.12	0.15	0.20	0.30	0.20
SW	0.43	0.31	0.25	0.23	0.31	0.46	0.33
RW	0.27	0.44	0.36	0.30	0.28	0.52	0.36
C	0.41	0.35	0.43	0.24	0.30	0.49	0.37
SW + C	0.43	0.45	0.48	0.30	0.35	0.46	0.41
RW + C	0.42	0.42	0.39	0.29	0.32	0.49	0.39
RWA	0.30	0.42	0.27	0.40	0.39	0.52	0.38

Table 7. Sound definition (D50) depending on the depth of air cavity behind absorptive panel.

Material	Hz	125	250	500	1k	2k	4k	AVG
lecture room (CC)		0.41	0.40	0.33	0.33	0.32	0.39	0.36
Aluminium Foam	Air cavity 20 mm	0.42	0.46	0.38	0.45	0.43	0.52	0.44
	Air cavity 70 mm	0.44	0.50	0.45	0.44	0.40	0.51	0.46
	Air cavity 140 mm	0.51	0.56	0.45	0.41	0.40	0.50	0.47

area than the side walls to increase the D50 values in spite of the relatively small amount of diffusers. The variation of D50 values at 500Hz lies from 0.34 to 0.41. This means that the sound clarity in an ordinary classroom can be effectively enhanced by the diffusers only.

Analyzing D50 of each measurement point, more clear difference was found at the rear area of the classroom. While D50 value at rear area is much lower (0.20) than the average overall value (0.33) at the current state, D50 values are increasing much when diffusers are put on any surfaces of the class-room. This means that the effects of sound diffusers on the sound clarity could be more obtained at the rear area of the classroom where is normally inferior to other area in acoustic conditions.

Varying the air cavity depth behind the absorptive panels on rear wall, it was found that the D50 value is slightly increasing with depth of air cavity. Es-pecially, the much difference of sound definition was occurred at the low frequency bands. This denotes that deep air cavity contributes to enhance the sound clarity at low frequencies (refer to Fig. 8 and Table 7).

3.4. RASTI

Average RASTI values of each measurement were illustrated in Fig. 9. As shown in Fig. 9, RASTI value is the lowest (0.485) in the current state(CC) and the highest (0.55) in RWA. Considering the RASTI values of each measurement with diffusers only, it is found that diffusive treatment on the both rear wall and ceiling is most effective for RASTI in com-parison with other areas. The diffusers on the side wall seem to be ineffective to enhance the sound clarity considering the amount of diffusers used.

As similar as D50, the difference of RASTI values at rear area of the classroom is much greater than other area when any diffusers or absorbers are put on any interior surfaces of the classroom. It was shown that, normally, 20 % of RASTI value is in-creased with absorption on rear wall and 10% of RASTI value is increased with diffusion.

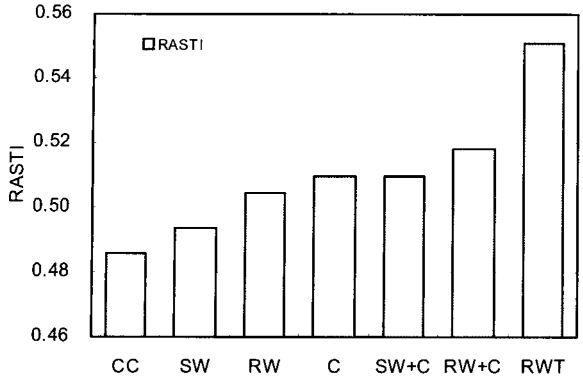


Fig. 9. Comparison of average RASTI of each measurement.

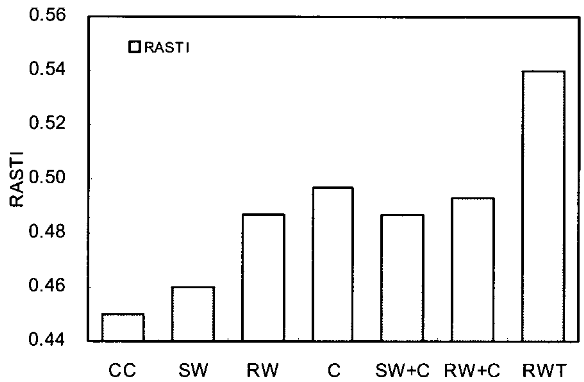


Fig. 10. RASTI values at the rear area of the classroom.

IV. Conclusions

Various diffusers are used in the acoustic experiments which are intended to find the appropriate area to enhance the sound clarity in classrooms. The results show that higher sound clarity was obtained when diffusers were applied to the both rear wall and ceiling rather than other areas in a classroom. It is also found that ceiling is more effective area than the side walls to increase the sound clarity in spite of the relatively small amount of diffusers. It can be concluded that diffusers can be used to enhance the sound clarity as well as to diffuse the sound in a classroom.

Also, it was confirmed that absorption increase sound clarity more effectively with smaller amount in comparison with diffusers. It was also found that the larger size of air cavity behind the absorptive panels can more effectively increase the sound definition at low frequencies. Thus, It was concluded that the effects sound diffusers and absorbers on the sound clarity could be obtained much at the rear area of the classroom where is normally inferior to other area in acoustic conditions.

References

1. J. T. Kim and C. H. Haan, "Investigation of the speech intelligibility of classrooms depending on the sound source location," *J. Acoust. Soc. Korea*, vol 24 no. 4E, pp. 139–143, 2005.
2. H. H. Lee and C. H. Haan, "Comparison of speech intelligibility depending on the sound source location in classrooms," in *Proc. of J. Acoust. Soc. Kor.*, vol. 21 no. 1, pp. 487–490, 2002.
3. S. R. Bistala and J. S. Bradley, "Predicting speech metrics in a simulated classroom with varied sound absorption," *J. Acoust. Soc. Am.*, vol. 109, pp. 1474–1481, 2001.
4. E. Sala & V. Viljanen, "Improvement of acoustic conditions for speech communication in classrooms," *Appl. Acoust.*, vol. 45, pp. 81–91, 1995.
5. M. Hodgson, "Experimental investigation of the acoustical characteristics of university classrooms," *J. Acoust. Soc. Am.*, 106, pp. 1810–1818, 1999.
6. S. B. SHIN and C. H. Haan, "Experimental Investigation of the Effects of Sound Diffusers on the Sound Clarity in Classrooms", in *Proc. of 9th WESPAC Conference*, Seoul, AR-2-6, 2006.
7. S. B. SHIN and C. H. Haan, "Effects of sound diffusers and panel absorbers on the sound clarity in classrooms", in *proc. of 19th ICA Conference*, Madrid, vol. 3, 2007.

[Profile]

• Sang-Bong Shin

Sang-bong Shin received BEng. in Architectural Engineering from Chungbuk National Univ. in 2005 and MEng. in 2007. He is to study at the Univ. of Florida for his Ph.D in 2009. His research interests include auditorium acoustics, classroom acoustics and acoustic modeling of buildings.

• Chan-Hoon Haan

Chan-hoon Haan received BEng. in Architecture from Hongik Univ. in 1983 and MEng. in architectural engineering from Yonsei Univ. in 1985. He obtained Ph.D in Architecture from University of Sydney in 1994. Since 1994, he has been a professor in the Architectural Engineering Dept., Chungbuk National University, Korea. He was also research fellow at the Salford Univ. UK in 2000-2001. His research interests include architectural acoustics and noise controls in buildings. Especially, he has involved in many architectural projects as an acoustic consultants.