Proceedings of the International Symposium on Room Acoustics, ISRA 2010

29-31 August 2010, Melbourne, Australia

Assessment of speech privacy in open plan offices

Joo Young Hong (1), Pyoung Jik Lee (1) Byung Kwon Lee (1) and Jin Yong Jeon (1)

(1) Department of Architectural Engineering, Hanyang University, Seoul 133-791, Korea

PACS: 43.50.Ba, 43.50.Qp, 43.50.Rq

ABSTRACT

The aim of this study was to find out the most appropriate single-number quantity assessing the speech privacy and to investigate the design factors affecting the speech privacy in open plan offices. At first, field measurements were conducted in open-plan offices in order to analyze the single-number quantities listed in ISO draft 3382-3; distraction distance, r_D, spatial attenuation rate of A-weighted SPL of speech per distance doubling, $DL_{2,S}$, and SPL of speech at a distance of 4 meters, $L_{p,S,4m}$. Then, laboratory experiments were carried out to investigate the effects of single-number quantities on the speech privacy in open-plan offices with variation of each single-number quantity. During the listening test, the subjects were asked to evaluate the speech intelligibility and listening difficulty; contributions of each single-number quantity to speech privacy were calculated and most appropriate single-number quantity was suggested. Finally, computer modeling was conducted in order to predict the objective measure for open plan offices.

INSTRUCTIONS

Nowadays, open plan office has become a common type of working space for a variety of businesses. Open plan office helps facilitate better communication between employees and is generally cheaper to fit out. But the high level of noise often causes disturbance and less concentration problems [1] and leads low productivity. At the same time, employees face the loss of privacy. Thus, it is important to achieve satisfisfation with acoustic quality of open-plan office. However there is no standardized method to evaluate acoustic condition in open-plan offices. In order to evaluate the acoustical condition of open-plan offices in terms of speech privacy, the objective measures such as signal to noise ratio and AI [2, 3] have been used according to ASTM E1130 and E2638. Recently, spatial measures were adopted in ISO draft 3382-3 as single number quantities [4]; distraction distance, r_D, spatial attenuation rate of A-weighted SPL of speech, $DL_{2,S}$, and SPL of speech at a distance of 4 meters, $L_{p,S,4m}$. However, the contributions of each single number quantity for speech privacy have not been fully investigated yet. Therefore, in the present study, the field measurement was conducted in two open-plan offices and the effects of single number quantities were investigated through auditory experiments by evaluation of speech intelligibility and listening difficulty. In addition, computer modeling was carried out to predict the objective measure in open plan offices.

FIELD MEASUREMENT

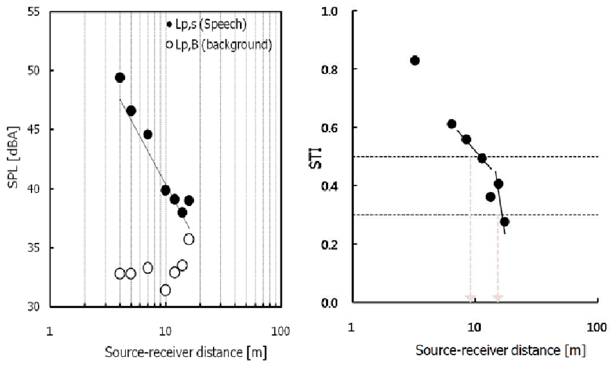
Measurement methods

Field measurements in two open plan offices were carried out in Seoul. As recently suggested in ISO 3382-3(DIS), the single number quantities listed in Table 1 were mearsured. Spatial attenuation rate of speech level per distance doubling, $DL_{2,s}$, and A-weighted speech level at a distance of 4m from the source, $L_{p,S,4m}$ were measured for speech privacy. STI calculated for speech intelligibility. Reverberation time, T_{20}, and Early decay time, EDT, were also measured. As shown in Figure 1, the measurements were conducted in unoccupied and funished open plan offices with HAVC noise. Omni-directional loudspeaker, producing pink noise, was used as a source. Omni-directional microphone and HATs were used as receivers. The microphones were positioned along a line which crosses over workstations. The measurement was made at height of 1.2 m.

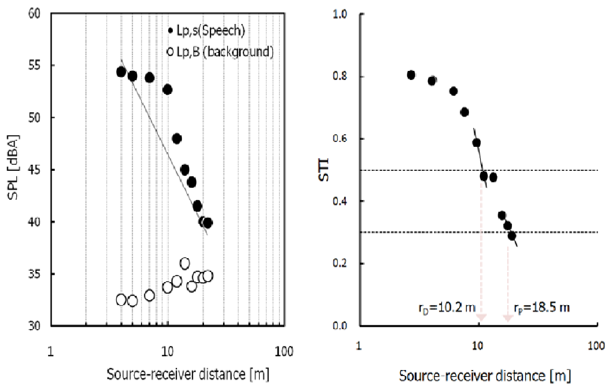
Table 1. Single number quantities for open-plan office

Parameter	Definitions
T_{20}	Reverberation time
EDT	Early decay time
$DL_{2,S}$	Spatial decay rate A-weighed SPL of speech
$L_{p,S,4m}$	A-weighted SPL of speech at a distance of 4 m
r_D	Distraction distance
r_P	Privacy distance
$L_{p,B}$	Background noise level
STI	Speech transmission index

Figure 1. Pictures of two open-plan offices



(a) Office #1



(b) Office #2

Figure 2. Field measurement results of two offices

Results

Figure 2 shows the results of the measurements. Upper two figures represent the results from office 1 and other two figures on the botton illustrate the results of office 2. As shown in Table 2, $DL_{2,S}$ was 0.38 and 0.41dB in office 1, 2 repectively thus, two offices obtained class D representing the lowest acoustic condition in accordance with acoustic classification and target values of open-plan offices proposed by Hongisto [5]. $L_{p,S,4m}$ of two offices were classified into class D by showing 59.6 and 54.4dB. However, both offices obtained class C in terms of r_D. It was found that proposed acoustic classification would not be agreement with respects to single number quantities.

Table 2. Measurement results of parameters

Office	T_{20}[s]	EDT[s]	$DL_{2,S}$[dB]	$L_{p,S,4m}$[dB]	r_D[m]
1	0.38	0.24	4.6	59.6	9.6
2	0.41	0.32	3.9	54.4	10.2

AUDITORY EXPERIMENT

Experimental design

Auditory experiment was designed to investigate the effects of $DL_{2,S}$ and $L_{p,S,4m}$. As illustrated in figure 3, $DL_{2,S}$ was varied from 43 to 57 dB as a step of 7dB and $L_{p,S,4m}$ were varied as 4, 8, 12dB. Thus, in total, 45 cases were conducted: 3 steps ($DL_{2,S}$) x 3 steps ($L_{p,S,4m}$) x 5 steps (level). Five sentences were presented to subjects in each case, HVAC noise with L_{eq} 30dBA recorded at office 1 was used as background noise. Speech sources recorded by female speaker in anechoic chamber were convolved with impulse reponses measured in office 1.

Procedure

Twenty subjects who have normal hearing in their 20s and 30s took part in listening test. Listening tests were carried out in a sound-isolated test room and all test sentences were presented in random order to subjects by headphone (Sennheiser HD 600). Subjects were asked to repeat the sentences which they thought that they had heard and to rate listening difficulty simultaneously. In order to measure the speech transmission, speech intelligibility test was adopted. Speech intelligibility score was calculated as the percentage of the words correctly understood or recognized by subjects after listening to the sentence. In this test, the intelligibility score was obtained by counting all words in the sentence considering the importance of every single word. Test sheet consisted of simple and short sentences to exclude the possiblitiy of the effect of sentence difficulty.

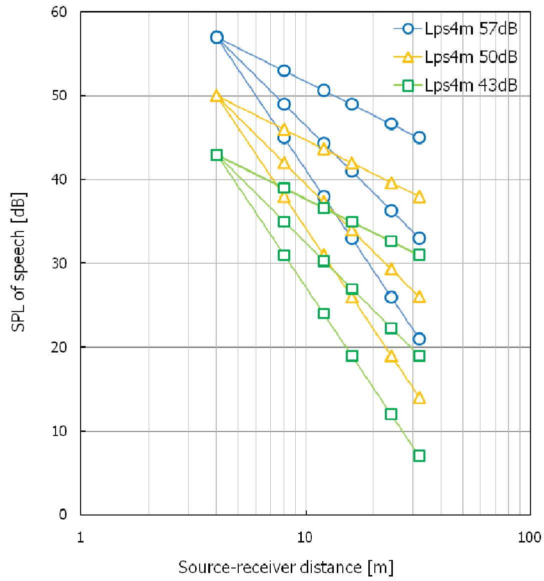


Figure 3. Variation of $DL_{2,S}$ and $L_{p,4m}$

However, speech intelligibility score has some disadvantages to evaluate speech privacy. For instance, although the intelligibility score is high, speech transmission performance is not always satisfactory. In order to solve this problem, Morimoto [6] suggested the listening difficulty rating as a subjective measure. For rating of listening difficulty, four categories are used from not difficult to extremely difficult. Listening difficulty rating is defined as the percentage of the sum of the difficulty responses 2, 3 and 4 except 1. Before the listening test, each subject trained for ten minutes to be accustomed to the test signals and background conditions.

Results

Figure 4 shows mean word intelligibility scores obtained from listening tests in terms of $DL_{2,S}$ and $L_{p,S,4m}$. From the results, it was found that speech intelligibility score decreased with an increase of $DL_{2,S}$. While $DL_{2,S}$ was kept constant, speech intelligibility score decreased as the value of $L_{p,S,4m}$ was declined. it was shown that speech intelligibility scores more dramticaly decreased when $DL_{2,S}$ changed from

8 to 12 dB than when it changed from 4 to 8 dB. This indicates that subjects were sensitive to changes of $DL_{2,S}$ in the range of 8 to 12 dB.

The two-way ANOVA for speech intelligibility scores was carried out to investigate the main effects of the two single number quantities. The result showed that $DL_{2,S}$ and $L_{p,S,4m}$ were statistically significant ($p<0.01$), and the effects of the interaction were not significant. Thus, $DL_{2,S}$ and $L_{p,S,4m}$ affected the speech intelligibility score independently, and the speech intelligibility scores could be given by equation (1)

$$\text{Speech intelligibility score} \approx f(DL_{2,S}) + f(L_{p,S,4m}) \approx a(DL_{2,S}) + b(L_{p,S,4m}) \qquad (1)$$

The standardized partial regression coefficients of $DL_{2,S}$ and $L_{p,S,4m}$ in Eq. (1) were -0.55 and 0.41, respectively, and these

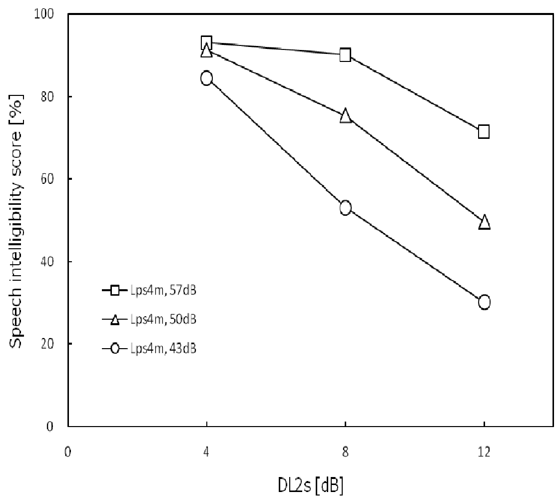


Figure 4. Relationship between speech intelligibilltiy score and single number quantities ($DL_{2,S}$ and $L_{p,4m}$)

coefficients were statistically significant ($p<0.01$ for a and b). Using these values, the obtained total coefficient 0.68 was significant ($p<0.01$). *Post hoc* comparisons via Tukey's test indicated that the differences between scores from 8 and 12 dB of $DL_{2,S}$, and 4 and 12 dB of $DL_{2,S}$ were significant ($p<0.05$), however, differences between scores from 4 and 8 dB of $DL_{2,S}$ were not significant.

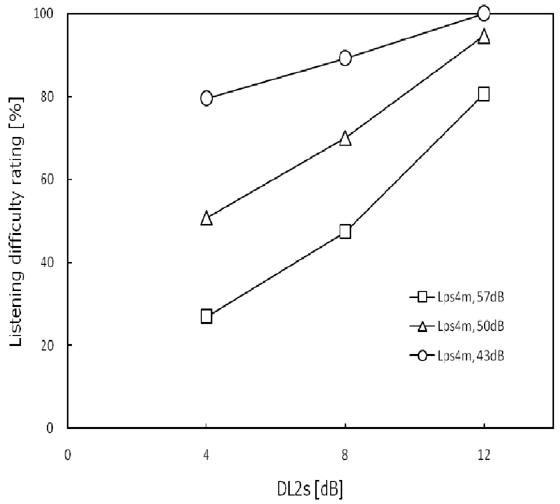


Figure 5. Relation between listening difficulty rating and single number quantities ($DL_{2,S}$ and $L_{p,4m}$)

Figure 5 shows the mean listening difficulty ratings obtained from the listening tests across all experimental conditions. Listening difficulty ratings increased with an increment of $DL_{2,S}$ and decreased as $L_{p,S,4m}$ increased. The results of two-way ANOVA for listening difficulty ratings represented that $DL_{2,S}$ and $L_{p,S,4m}$ are statistically significant ($p<0.01$), and the effects of the interaction between them were not significant. As the listening difficulty rating is a dependent variable, the relationship between listening difficulty and $DL_{2,S}$ and $L_{p,S,4m}$ is given by equation (2).

$$\text{Listening difficulty rating} \approx f(DL_{2,S}) + f(L_{p,S,4m}) \approx a(DL_{2,S}) + b(L_{p,S,4m}) \qquad (2)$$

The standardized partial regression coefficients of $DL_{2,S}$ and $L_{p,S,4m}$ in Eq. (2) were 0.56 and -0.54, respectively, and these coefficients were statistically significant ($p<0.01$ for a and b). A post hoc Tukey's test showed that the differences between ratings were all significant ($p<0.05$) except for the difference between 4 and 8 dB of $DL_{2,S}$.

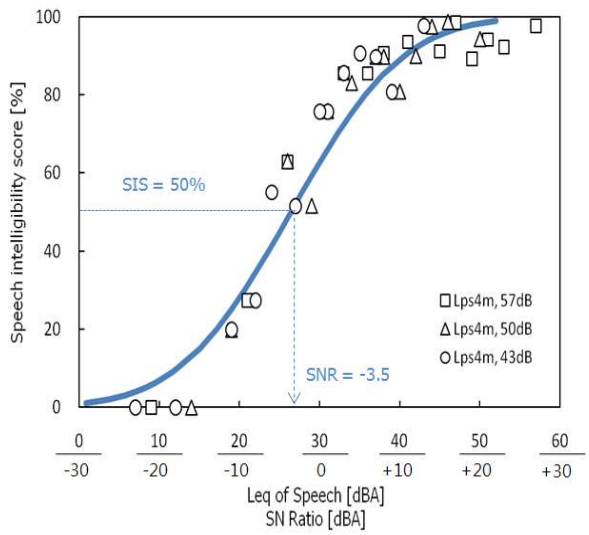


Figure 6. Relation between speech intelligibilltiy score and SN Ratio

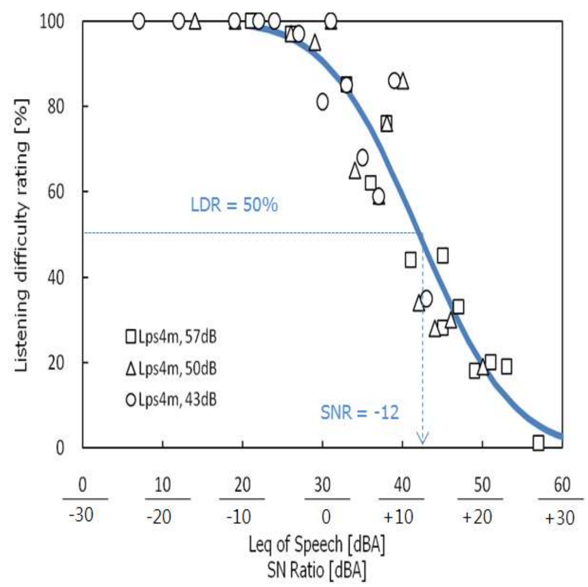


Figure 7. Relation between listening difficulty rating and SN Ratio

Figure 6, 7 represent speech inelligibility socre and listening difficulty rating as a function of SN ratio. As shown in the figures, speech inelligibility socre sharply decreased when SN ratio is below 0.(50%=-3.5) and listening difficulty dramatically decreased when SN ratio is above 0. (50%=12).

COMPUTER MODELING

Computer modeling was undertaken by using Odeon 10.01. As shown in Figure 8, measured STI values showed a good agreement with predicted values obtained from computer simulation. This indicates that computer simulation can be applicable to the prediction of objective measure for speecy privacy in open plan office. Therfore, in the future, the effects of design factors illustrated in Figure 9 such as partition height, absorption of partition on speech privacy will be considered through computer simulation.

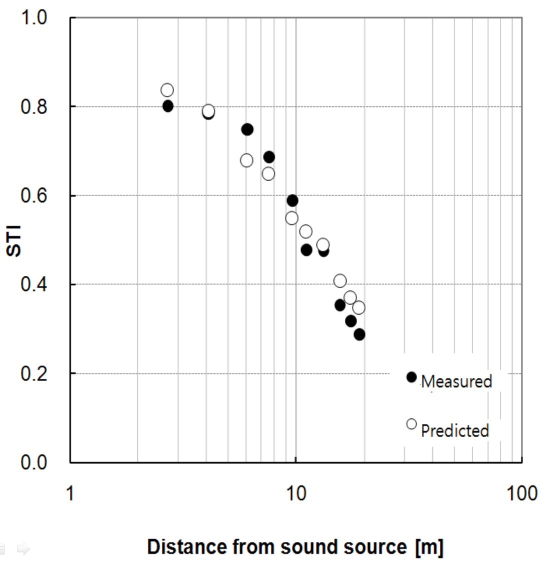


Figure 8. Measured and predicted STI

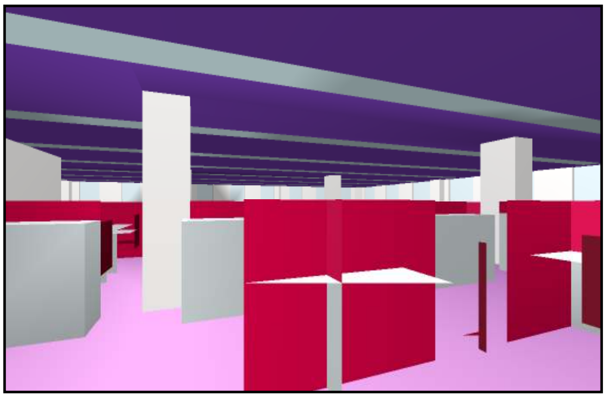


Figure 9. Computer modeling of open-plan offices

SUMMARY

In this study, field measurements were conducted in two open-plan offices located in Seoul to evaluate the acoustical conditions in terms of room acoustic single number quantities presented in ISO 3382-3 draft. The acoustical quality of two open-plan offices obatined different acoustic class in respects of $DL_{2,S}$ and r_D. The auditory experiments were also carried out to investigate the effects of $DL_{2,S}$ and $L_{p,S,4m}$ on speech privacy in open-plan offices. It was found that $DL_{2,S}$ and $L_{p,S,4m}$ affected speech intelligibility and listening difficulty independently, and the contribution of $DL_{2,S}$ to speech privacy was slightly larger than $L_{p,S,4m}$. It was also found that computer simulation can be applicable to predict the objective measure in open plan offices.

REFERENCES

1 Helenius R.; Keskinen E.; Haapakangas A.; Hongisto V.A.N., "Acoustic environment in Finnish offices - the summary of questionnaire studies", 19th International Congress on Acoustics, Madrid, Spain (2007)

2 Cavanaugh W.J.; Farrell W.R.; Hirtle P.W.; Watters B.G., *"Speech Privacy in Buildings" J. Acoust. Soc. Am.* **34**, 475-492 (1962)

3 ANSI S3.5; *American National Standard Methods for the calculation of the articulation index, Standards Secretariat, Acoustical Society of America*, New York, USA (1969)

4 ISO draft 3382-3; *"Acoustics — Measurement of room acoustic parameters — Part 3: Open plan spaces", International Standard Organization, Geneva* (2010)

5 Virjonen P.; Keränen J.; Hongisto V., *"Determination of acoustical conditions in open-plan offices: proposal for new measurement method and target values", Acta Acustica.* **95**, 279-290 (2009)

6 Morimoto M.; Sato H.; Kobayashi M.; *"Listening difficulty as a subjective measure for evaluation of speech transmission performance in public spaces", J. Acoust. Soc. Am.* **116,** 1607-1613 (2004)