Designing and assessing speech privacy in open-plan offices
Bradley, J. S.

Proceedings 19th International Congress on Acoustics, pp. 1-6, 2007-09-02

Designing and assessing speech privacy in open-plan offices

NRCC-49499

Bradley, J.S.

A version of this document is published in / Une version de ce document se trouve dans:
19th International Congress on Acoustics, Madrid, Sept. 2-7, 2007, pp. 1-6

DESIGNING AND ASSESSING SPEECH PRIVACY IN OPEN-PLAN OFFICES

PACS: 43.55.Hy

Bradley, John S.
National Research Council, 1200 Montreal Rd., Ottawa, Canada, K1A 0R6
John.Bradley@nrc-cnrc.gc.ca

ABSTRACT
Better speech privacy in open-plan offices can be most consistently achieved by a combination of quantitative design procedures and validation measurements. This has not always been done in the past because of the lack of convenient design and measurement tools. While signal-to-noise type measures such as the Articulation Index have been used to indicate the amount of speech privacy in North American offices, often Speech Transmission Index values have been used in European offices. This paper reviews the relationships among speech privacy measures and between these measures and the geometrical and acoustical properties of open-plan office workstations. Speech privacy criteria for open-plan offices are also related to the expected intelligibility of speech from a neighbouring workstation. Finally, new computer-based tools to aid in the design and measurement of the speech privacy in open-plan offices are described.

INTRODUCTION
The acoustical quality of an open-plan office can best be related to signal-to-noise type measures [1] such as the Articulation Index (AI) [2] because the primary design goal is to minimize the intelligibility and disturbance of unwanted speech sounds from nearby workstations. Although speech levels in open plan offices tend to be lower than normal voice levels [3], ambient noise levels must also be limited to acceptable values. If ambient noise levels are too low, signal-to-noise ratios will be too high and speech privacy will be inadequate. If ambient noise levels are too high, there may be a high level of speech privacy but ambient noise levels will be disturbing and cause people to talk more loudly. Previous studies [4-6] have led to a recommended optimum ambient noise level of 45 dBA and an AI of no more than 0.15.

Although similar design recommendations have been available for many years, designs are rarely made in a quantitative manner to meet such specific criteria and even more rarely are they verified by post occupancy measurements. A quantitative approach would indicate the magnitude of successes and failures as well as lead to a better understanding of the effects of various parameters on the desired speech privacy.

SIGNAL-TO-NOISE RATIOS
Although the AI is included in various ASTM standards for measurements in open-plan offices, the ANSI standard defining it [2] has been revised and the new measure is referred to as the Speech Intelligibility Index (SII) [7]. Figure 1 plots measured SII values versus the corresponding AI values, all determined from measured attenuations between adjacent workstation for the same speech source levels and ambient noise levels. SII values tend to be about 0.06 larger than AI values except at very low values where the two quantities both approach 0.

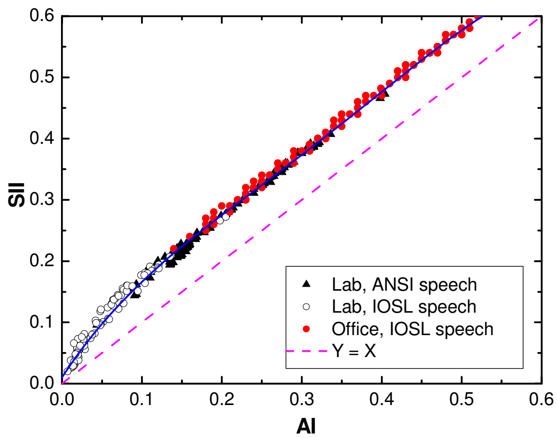

Figure 1. Measured SII values versus measured AI values for sound propagation between adjacent workstations.

The AI and SII measures are frequency weighted signal-to-noise ratios transformed to have values between 0 and 1. The Speech Transmission Index (STI) has similar roots but also includes the effects of reverberant speech as a contribution to the noise component. In acoustically dead conditions STI values would be expected to be similar to AI values but when there is significant reverberant speech sound, STI values would be systematically reduced relative to the corresponding AI values. Figure 2 plots measured STI values versus AI values for adjacent workstations in two environments, all determined for the same speech source levels and ambient noise levels. In neither case was there significant reverberant speech sound but in the small office there would be some early arriving speech reflections from the walls of the office.

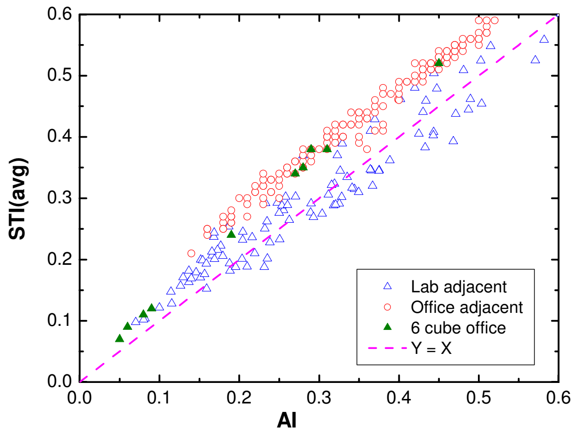

Figure 2. Measured STI values versus measured AI values between adjacent workstations in and acoustically dead lab space and a small open-plan office.

Listening tests determined the intelligibility of test sentences from conditions simulating transmission from an adjacent workstation. Figure 3 plots mean speech intelligibility scores versus the SII and AI values of the conditions [8] aggregated in 0.05 intervals. The shaded area indicates desired conditions with AI ≤ 0.15 (approx. SII ≤ 0.20). By re-measuring the experimental conditions, it was possible determine STI values for each condition and to relate mean speech intelligibility scores to these STI values as shown in Figure 4.

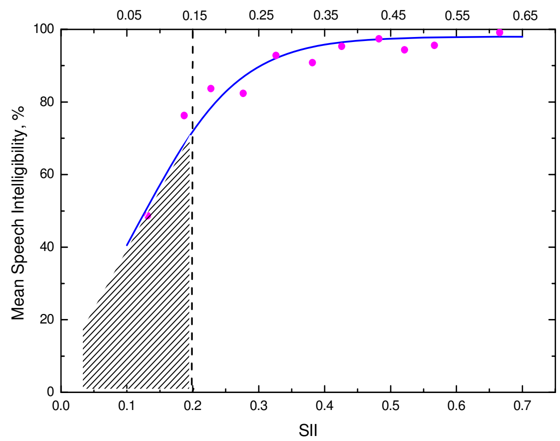

Figure 3. Mean speech intelligibility scores versus AI and SII values aggregated in 0.05 intervals.

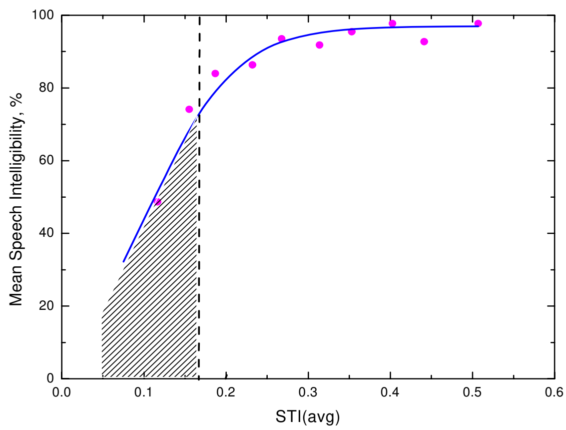

Figure 4. Mean speech intelligibility scores versus STI values aggregated in 0.05 intervals.

EFFECTS OF OFFICE DESIGN PARAMETERS

This section presents the results of measurements of systematic changes to key open-plan office design parameters. These were previously analyzed in terms of measured AI and SII values [9]. New analyses of impulse response measurements made at time of the original measurements have made it possible to also show the effects of parameter variations in terms of STI values. Although the complete STII includes the effects of reflected speech sounds as well as speech and noise levels, it is possible to consider the effects of reflected sound separately. STI values were first calculated from the impulse responses without any significant noise level. Because the measurements were made between two adjacent workstations in an acoustically dead space the amount of reflected sound energy is quite small and the partial STI values from the impulse responses only (referred to as STI(imp)) are very high (typically 0.90 to 0.98). In spaces with significant reverberant sound these STI(imp) values could be much lower.

Figure 5 plots the effects of varying the ceiling absorption for measurements between adjacent workstations with all other parameters constant. Ceiling absorption is described in terms of the sound absorption average SAA [10]. The upper plot shows that AI, SII and STI values decrease with increasing ceiling absorption corresponding to increasing speech privacy. Although the results for AI and SII follow parallel trends, the STI values vary slightly less rapidly with increasing SAA. The lower graph of the figure shows that the reflected sound component does not vary and STI(imp) values are almost constant with varying ceiling SAA.

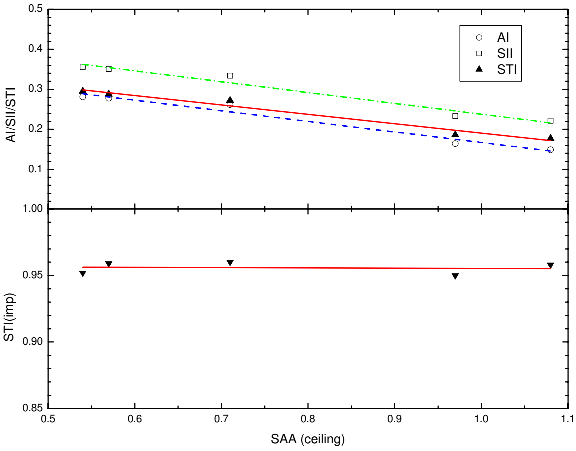

Figure 5. Effects of varied ceiling absorption (SAA) in terms of AI, SII and STI values (upper graph) and effects on STI(imp) in the lower graph.

In Figure 6 the measured effects of varied workstation panel absorption are shown. Again increased absorption, in this case for the workstation panels, leads to lower AI, SII and STI values and to improved speech privacy. The lower plot shows that when the sound absorption of the workstation panels is increased, the STI(imp) values also increase. Although one might expect this to correspond to decreased privacy, the larger effect that reduces transmitted speech levels will decrease complete STI values and increase privacy as shown in the upper graph. Thus using STI measurements can provide a more complete understanding of the conditions but could be confusing.

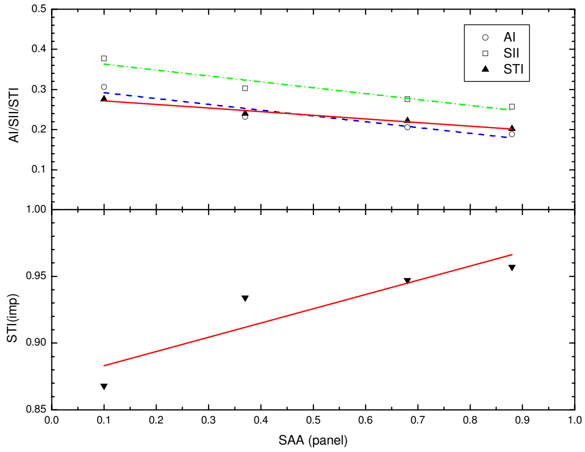

Figure 6. Effects of varied panel absorption (SAA) in terms of AI, SII and STI values (upper graph) and effects on STI(imp) in the lower graph.

The effects of the workstation plan size and panel height are illustrated in Figure 7. For these measurements between two adjacent square workstations, increasing the workstation plan size (length of one side of the workstations) leads to reduced transmitted speech levels and hence lower AI, SII and STI values as shown in the lower graph of this figure. However, the upper graph in Figure 7 shows that the AI, SII and STI values are more sensitive to the variation in panel height. Increased panel height reduces the levels of diffracted speech sounds from the adjacent workstation and hence reduces AI, SII and STI values leading to improved speech privacy.

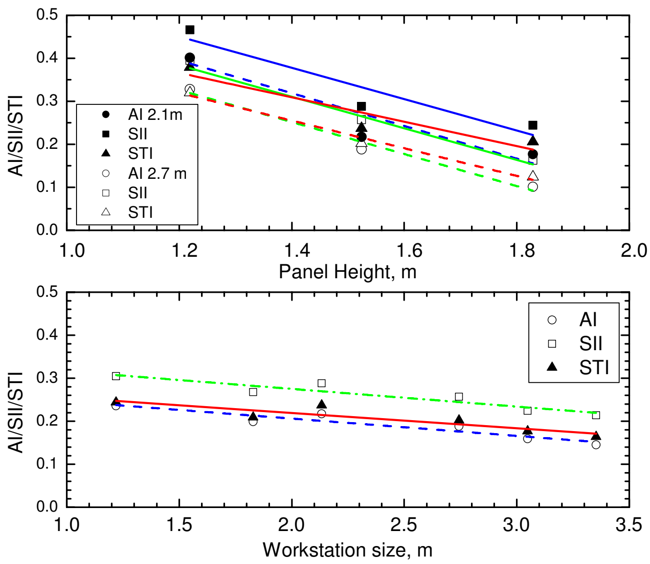

Figure 7. Effects of varied panel height in terms of AI, SII and STI values (upper graph) and effects workstation plan size in the lower graph.

NEW TOOLS

To make it practical to design open-plan offices in a quantitative manner, a model of sound propagation between workstations was developed [11-14] based on image sources principles. Because all important sound paths are included, this model has been found to agree well with measurements in real offices. The model has been incorporated into an easy to use computer program, COPE-Calc that is available without charge [15].

The other tool that is needed to improve the acoustical conditions in open-plan offices is a convenient means of measuring the privacy of existing offices to verify the success of the design. Such a tool is being developed and measures AI, SII and STI values within open-plan offices using and impulse response technique. This makes it possible to measure STI values as well as AI and SII values and is also intended to make it possible to make measurements during the daytime when the office is occupied. Because measurements are more rapidly made, studies such as the contours of AI values shown in Figure 8 can be obtained to help understand sound propagation in open-plan offices.

CONCLUSIONS

Following quantitative design procedure and subsequent measurements of the resulting offices is most likely to lead to improved speech privacy in open-plan offices. New design and measurement tools now make this conveniently possible. Using STI values rather than AI or SII values makes it possible to evaluate a wider range of conditions that include significant amounts of reflected sound in the office space. However, conditions in spaces with significant reflected sound will not meet the desired speech privacy goals.

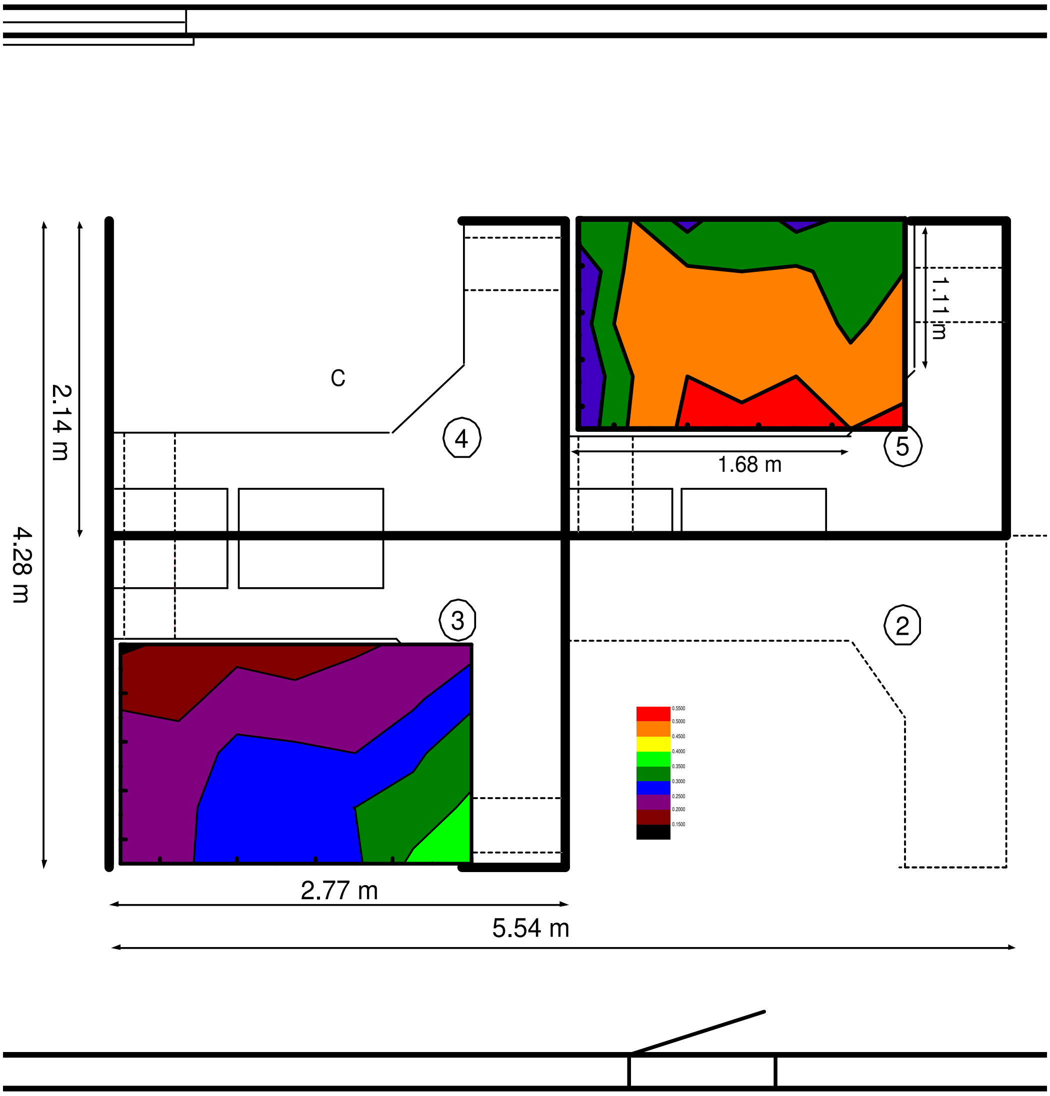

Figure 8, Contours of AI values for propagation from workstation #4 to workstations #3 and #5 from measurements at 0.30 m intervals. (Figure shows part of a 6 workstation open-plan office).

References

1. Cavanaugh, W.J., Farrell, W.R., Hirtle, P.W., and Watters, B.G., "Speech Privacy in Buildings", J. Acoust. Soc. Am. 34 (4), 475-492 (1962).
2. ANSI S3.5-1969, American National Standard Methods for the Calculation of the Articulation Index, Standards Secretariat, Acoustical Society of America, New York, USA.
3. Warnock, A.C.C. and Chu. W, "Voice and Background Noise Levels Measured in Open Offices", IRC Report IR-837, January 2002.
4. Bradley, J.S., "A Renewed Look at Open Office Acoustical Design", Paper N1034, Proceedings Inter Noise 2003, Seogwipo, Korea, August 25-28, 2003.
5. Bradley. J.S., "The Acoustical Design of Conventional Open Plan Offices", Canadian Acoustics, 27(3) 23-30 (2003).
6. Bradley, J.S., "Acoustical Design for Open-Plan Offices", Construction Technology Update, (63), pp 6, 2004 (NRCC-). Also in French, «Acoustique des bureaux à aire ouverte».
7. ANSI S3.5-1997, "Methods for Calculation of the Speech Intelligibility Index", American National Standard, Standards Secretariat, Acoustical Society of America, New York, USA.

8. Bradley, J.S, and Gover, B.N, "Describing Levels of Speech Privacy in Open-Plan Offices", Institute for Research in Construction, National Research Council, Ottawa, report, IRC-RR-138, (2003).
9. J.S. Bradley and C. Wang, "Measurements of Sound Propagation between Mock-Up Workstations", April 2000, IRC RR-145.
10. Sound absorption average, SAA, is defined in ASTM C423-99a, "Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method", American Society for Testing and Materials, Philadelphia, USA.
11. Wang, C. and Bradley J.S., "A Mathematical Model for a Single Screen Barrier in Open-plan Offices", Applied Acoustics, 63(8), pp. 849-866 (2002).
12. Wang, C. and Bradley, J.S., "Prediction of the Speech Intelligibility Index Behind a Single Screen in an Open-plan Office", Applied Acoustics, 63(8), pp. 867-8832.
13. Wang, C. and Bradley J.S., "Sound Propagation between Two Adjacent Rectangular Workstations in an Open-plan Office, I: Mathematical Modeling", Applied Acoustics 63, 1335-1352 (2002).
14. Wang, C. and Bradley J.S., "Sound Propagation between Two Adjacent Rectangular Workstations in an Open-plan Office, II: Effects of Office Variables", Applied Acoustics 63, 1353-1374 (2002).
15. COPE-Calc software is available at *http://irc.nrc-cnrc.gc.ca/ie/cope/07_e.html*