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Architectural Speech Security of Offices and Meeting Rooms

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Abstract

This paper gives an overview of ongoing work on the architectural speech security of offices and meeting rooms. A room is said to be speech secure when eavesdroppers outside the room cannot understand or even not hear speech sounds transmitted from within the meeting room. The ultimate goal of this work is to be able to design for adequate speech security in new rooms and to be able to accurately assess the speech security of existing rooms. The work includes determining the statistical characteristics of the levels of the speech in meeting rooms and of the ambient noise in spaces near meeting rooms. Proposed procedures for predicting the speech security of new spaces are presented and the problems of developing a measurement procedure for assessing speech security in existing rooms are discussed.

Introduction

This paper gives an overview of ongoing work on the architectural speech security of meeting rooms and offices. In many such rooms it is intended that conversations within the room should be private and not audible to others outside the room. To prevent eavesdropping, it is important that the complete envelope of the room provides adequate sound insulation to make it impossible for someone outside the room to understand speech from within the room. Speech security can be thought of as a higher level of speech privacy. Speech privacy usually refers to situations where the intelligibility of speech is reduced but is still partially understandable. When we want to achieve speech security, we must ensure that the speech cannot be understood at all and in some cases we may want speech sounds from an adjacent room to be completely inaudible.

To design new rooms, or to evaluate the architectural speech security of existing meeting rooms requires several key pieces of information. The intelligibility or lack of intelligibility of speech at some location is primarily related to how loud the speech is relative to the level of ambient noise at that point. Therefore, we need to know the characteristics of, the speech that has propagated from the meeting room, and the noise that is found in spaces near the meeting room. Of course both of these quantities can vary over a large range and hence the problem becomes one of understanding the probability of particular speech and noise levels occurring. The level of the speech from the meeting room depends not only on how loud people talk in the meeting room, but also on how much speech sound is transmitted through the various elements of the room boundary into adjacent spaces. Sometimes the propagation path may be quite simple such as through a leaky door, but at other locations it may be a more complex path such as through ventilation ducts or via parts of the building structure.

The goals of our current work on architectural speech security are as follows:

(a) To develop statistical descriptions of the probability of various speech levels occurring in meeting rooms both with and without sound amplification systems.
(b) To determine a representative spectrum shape for speech sounds in meeting rooms.
(c) To develop statistical descriptions of the probability of various ambient noise levels occurring in spaces near meeting rooms.
(d) To determine a representative spectrum shape for ambient noise in spaces near meeting rooms.
(e) To develop a measurement procedure for evaluating the architectural speech security of meeting rooms and offices.
(f) To develop a procedure for predicting the expected speech security of offices and meeting rooms.
(g) To develop a new measure from the spectra of the transmitted speech and the ambient noise that best relates to subjective ratings of speech intelligibility and audibility.
(h) To develop criteria based on the new speech security measure that relate to specific degrees of speech security. That is, criteria that indicate what would be audible and intelligible to those trying to eavesdrop.

Much of the work is still in progress so this paper gives an overview of the complete project with more details in areas where work has progressed further. Many of the results presented here are tentative and may change when analyses are complete.

Speech Levels in Meeting Rooms

One of the first tasks was to characterize speech levels in a wide range of meeting rooms both with and without sound amplification systems. This was done by monitoring A-weighted sound levels in meeting rooms over 24 hour periods and using appropriate published results for the speech spectrum shapes. Four sound level loggers were located in each meeting room and recorded values of Leq, L10, and L90 at 10 s intervals for A-the weighted sound levels. The loggers were mostly located to measure the level of speech sounds incident on the boundaries of the rooms. A wide range of room sizes and types of meeting were measured as summarized in Table 1.

Number of meeting room cases* measured	32
Number of meetings measured	79
Number of people in each meeting	2 to 300 people
Range of room volumes	39 to 16,000 m^3
Range of room floor areas	15 to 570 m^2

*Table 1. Summary of meeting rooms measured. (* includes 30 different rooms, 2 of which were measured with and without sound amplification systems).*

Figure 1(a) shows an example of the recorded Leq values over 10 s intervals for a complete 24 hour period showing two different meeting events. Figure 1(b) shows an enlarged version of the time history of the 10 s Leq values for one of the meetings. Clearly there is much variation of the speech levels over time and it is desirable to consider them in a statistical manner.

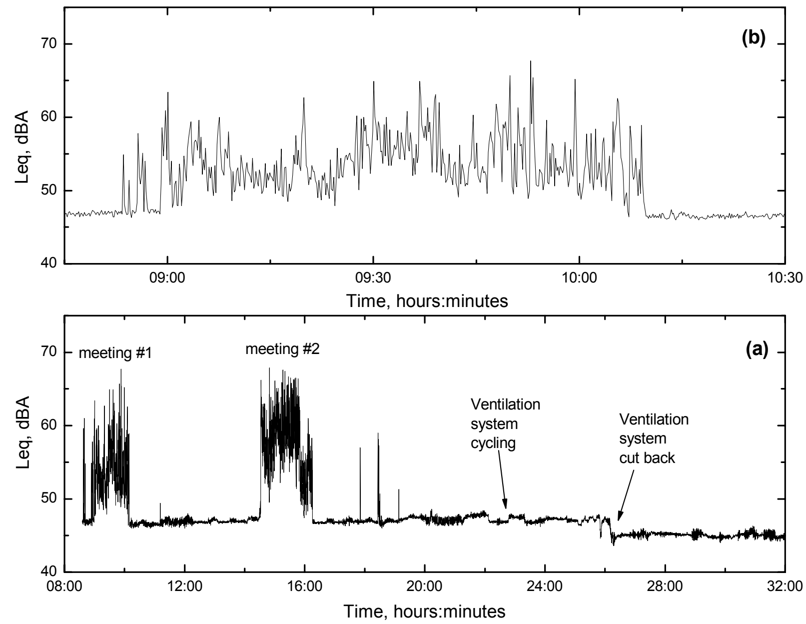

Figure 1. Recorded time history of 10 s Leq values from one logger, (a) complete 24 hour period, (b) enlarged portion for one meeting. (Hours greater than 24 indicate next day).

Figure 2 illustrates the distribution of levels for the same meeting as in Figure 1(b) as a histogram and a cumulative distribution (CPD) curve. From this type of CPD plot we can directly read of the probability of various speech levels occurring.

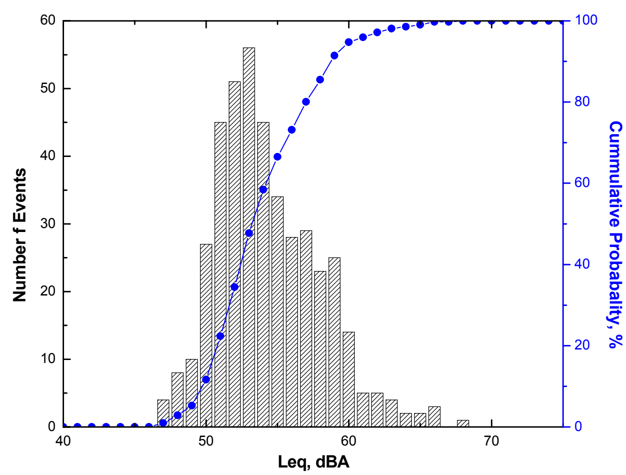

Figure 2. Distribution of 10 s Leq values from meeting shown in Figure 1(b) as a histogram of the number of times each value occurred (left hand axis) and a cumulative probability plot (right hand axis).

As well as the detailed Leq values at 10 s intervals, the overall Leq of the speech levels for each meeting, averaged over the measurements at all four sound level loggers, were also calculated and are referred to as meeting average Leq values. Table 2 gives a summary of these meeting average measured values of the meeting room speech Leq values. The average speech Leq values for the various types of meetings were generally quite similar.

Condition	Meeting average speech level, Leq, dBA	Standard deviation, dBA	Number of meetings, N
All meetings	60.7	4.1	79
All amplified meetings	62.0	4.5	29
All Non-amplified meetings	60.0	3.4	50
Non-amplified small rooms	61.1	2.6	26
Non-amplified large rooms	58.3	3.4	24
Amplified: single loudspeaker system	62.1	4.4	14
Amplified: multiple loudspeaker system	61.8	4.8	15

Table 2. Meeting average sound levels (Leq, dBA) for various amplified and non-amplified conditions with the standard deviation of each group of N meetings.

Perhaps surprisingly, speech levels where sound amplification was used were on average only 2.0 dB higher than for meetings where no amplification was used. However, in two meeting rooms where both amplified and non-amplified meetings were measured, the effect of the sound amplification was to increase speech levels by approximately 10 dB. Thus, the sound amplification systems do increase levels, but in general they seem to be used to bring up the speech levels to equal or slightly exceed the natural speech levels found in smaller rooms.

It was verified that the L90 values recorded during meetings were representative of the general ambient noise levels in the meeting rooms when there was not a meeting. Figure 3 shows that measured speech Leq values for meetings systematically increase with the general ambient noise level as determined from the L90 values obtained during the meetings. This illustrates a well-known effect known as the Lombard effect that describes how talkers naturally raise their voice level in noisier environments. Although this has obvious implications for the quality of speech communication in the meeting rooms, it also has implications for speech security. These results indicate that where there is louder ambient noise in the meeting room, talkers will talk more loudly, which is more likely to be overheard outside the meeting room. It is therefore important to ensure that ambient noise levels in meeting rooms are relatively low. Of course higher levels of ambient noise outside the meeting room would also help to achieve good speech security.

The speech level data were extensively analysed to look for systematic effects of room size and of the numbers of occupants on the resulting speech levels. Although some small effects were found, none were of great practical significance. Therefore, the 10 s Leq values of speech levels incident on the boundaries of the meeting rooms were all grouped together and only considered separately in two groups: amplified and non-amplified meetings.

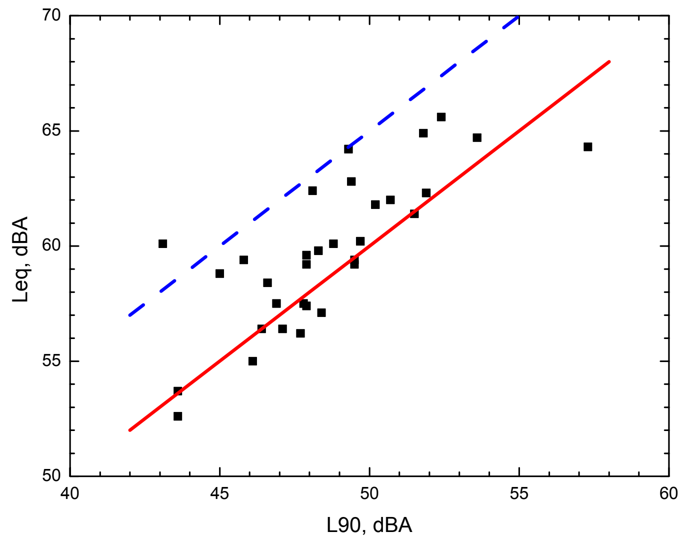

Figure 3. Meeting room speech levels (Leq) versus ambient noise levels in the meeting rooms (L90). The solid line shows situations with a 10 dB speech-to-noise ratio and the dashed line shows the more ideal case of a 15 dB speech-to-noise ratio.

The probabilities of the occurrence of various speech levels were then obtained by calculating cumulative probability distributions similar to that in Figure 2, but for the speech data from all 79 meetings. For non-amplified meetings there were a total of 66,366 ten-second speech Leq values, for the amplified meetings there were 44,415 Leq values and for the combined data there were 110,781 Leq values. The resulting cumulative probability curves are included in Figure 4. Figure 4(a) shows the complete distributions and Figure 4(b) shows an enlarged version of the critical upper parts of the curves.

One can read off the probability of various speech levels occurring directly from these graphs. For example, the combined data indicates that the 90th percentile is about 64.4 dBA. That is, only 10% of the values exceed a speech level of 64.4 dBA. Similarly only 5% of the values exceed 66.7 dBA and only 2% of the speech levels exceed 69.3 dBA. One can similarly read off slightly lower values for the non-amplified cases and a little higher values for the amplified meeting cases.

Having established the probability of various speech levels occurring in meeting rooms, a representative spectrum shape for the speech in the meetings rooms was obtained by using an average of the male and female raised voice level spectra from data by Pearsons et al. [1]. Using this spectrum shape, the overall level was adjusted to correspond to a particular level from the cumulative probability distribution plots in Figure 4. Figure 5 shows the resulting speech spectra for 75th, 90th, 95th, and 98th percentile speech levels. The 75th percentile level in this case corresponds to the overall average Leq of all meeting speech levels in Table 2.

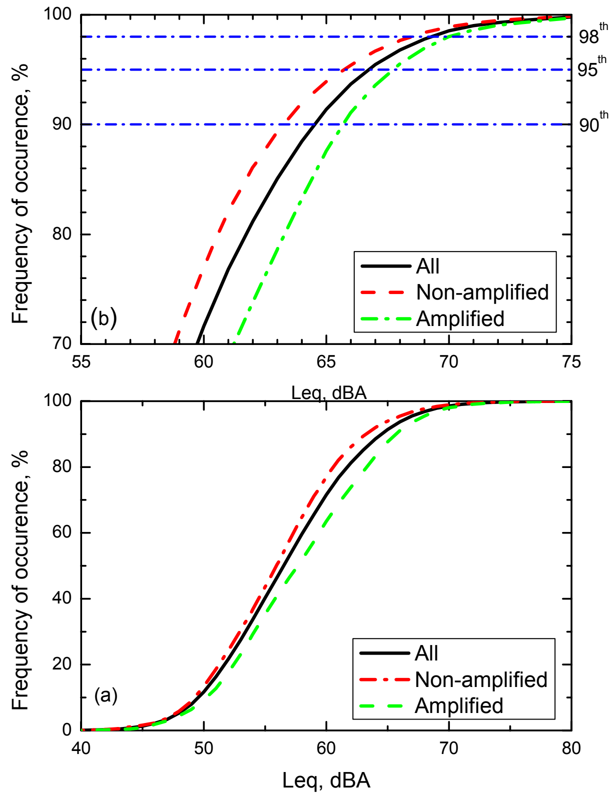

Figure 4. Cumulative probability curves obtained from all 10 s speech Leq values as well as separate results for all amplified and all non-amplified meetings. The upper curve shows an enlarged version of the upper portion of the complete distributions and indicates the 90th, 95th and 98th percentile levels.

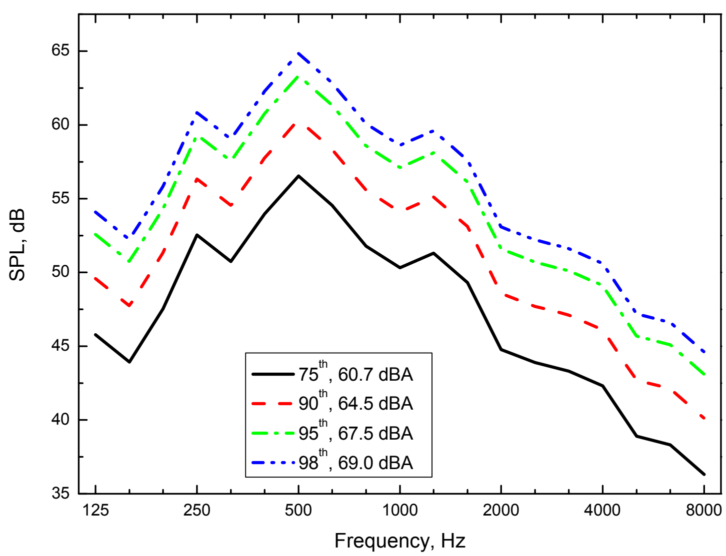

Figure 5. New average speech spectrum shape for speech security calculations shown adjusted in level to correspond to various percentile speech levels.

Noise Levels in Spaces Near Meeting Rooms

Ambient noise levels near meeting rooms were assessed using the same 24 hour sound level loggers and also by a large number of 1/3 octave band measurements of specific situations. Table 3 gives a summary of the average A-weighted noise levels for various times of day. As expected ambient noise levels are lowest during the nigh time hours and highest during the day time hours.

Measure	**Day** **(8:00 – 17:00)**	**Early evening** **(17:00 – 21:00)**	**Late evening** **(21:00 – 24:00)**	**Night** **(24:00- 6:00)**
Average Leq, dBA	49.1	45.9	43.4	43.1
Standard deviation, dB	4.5	5.0	5.3	5.7

Table 3. Summary of average ambient noise levels in terms of Leq values for each period of the day. The standard deviations indicate the variation within each category.

Cumulative probability plots of the measured noise levels were also calculated for each time of day period and are shown in Figure 6. This plot can be used to estimate the probability of various noise levels occurring during each time of day period. The results in Figure 6 indicate, on average, that a background ambient noise level of 30 dBA (in terms of 10 s Leq values) is exceeded about 90% of the time during the night, 93% of the time during the late evening, 96% of the time during the early evening, and almost all of the time during the day. If one assumes that most meetings occur during the day or early evening, and that the 5^{th} percentile level indicates an adequate degree of security, then one should design for the case of ambient noise levels of at least 31 dBA. The results should then be representative of a wide range of meeting rooms found in Canadian institutional buildings.

The results from the sound level loggers give precise results concerning the probability of various ambient noise levels occurring at various times of day in terms of A-weighted sound levels. To acquire information about the spectral characteristics of the noise, a total of 347 one-third octave band spectra were measured at locations near meeting rooms and at various times of day. These results were grouped into categories corresponding to 5 types of noise.

Figure 7 shows a summary of the results for four of these types of noise: (a) ventilation noise, (b) indoor road traffic noise, (c) computer related equipment noise, and (d) noise of refrigerators and cold drink machines. Each plot shows the overall mean spectrum with bars to indicate the standard deviation about this mean. Also shown is a –5 dB/octave reference line. This –5 dB/octave spectrum line is said to approximate a neutral spectrum noise and as indicated in Figure 7 is usually a good approximation to ventilation type noises [2,3]. The fifth type of ambient noise was miscellaneous office sounds, which very closely matched this –5 dB/octave spectrum shape. The numbers of measurements of each type of noise are given in Table 4.

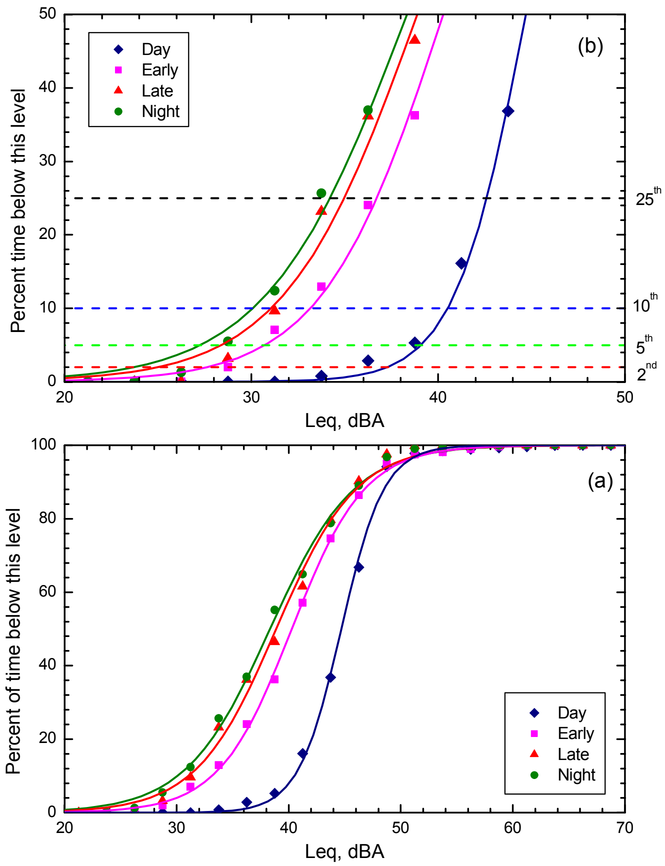

Figure 6. Cumulative probability plots of A-weighted noise levels for each of four different time-of-day periods. Figure 6(a) shows the complete curves and Figure 6(b) shows an enlarged version of the more critical lower portion of the distributions.

While there are some deviations, the average spectra for each of the 5 types of noises all approximate the –5 dB/octave reference spectrum. In only a very small number of cases are the measured 1/3 octave band values more than 1 standard deviation from this line. If the overall average of all of the 5 spectra is calculated, it is very close to a –5 dB/octave spectrum shape. This –5 dB/octave spectrum shape is therefore recommended for use in speech security design calculations. One should pick an ambient noise level from the cumulative probability plots in Figure 6, and then use an ambient noise with this overall level and a –5 dB/octave spectrum shape. Figure 8 shows the results of this process for the 2nd, 5th, 10th and 25th percentile noise levels for the early evening time period.

Type of noise	**Number of measurements**
Ventilation	183
Computer related	24
Indoor road traffic	53
Miscellaneous office	63
Refrigerators and coolers	24
Total	347

Table 4. Summary of 1/3 octave band ambient noise measurements.

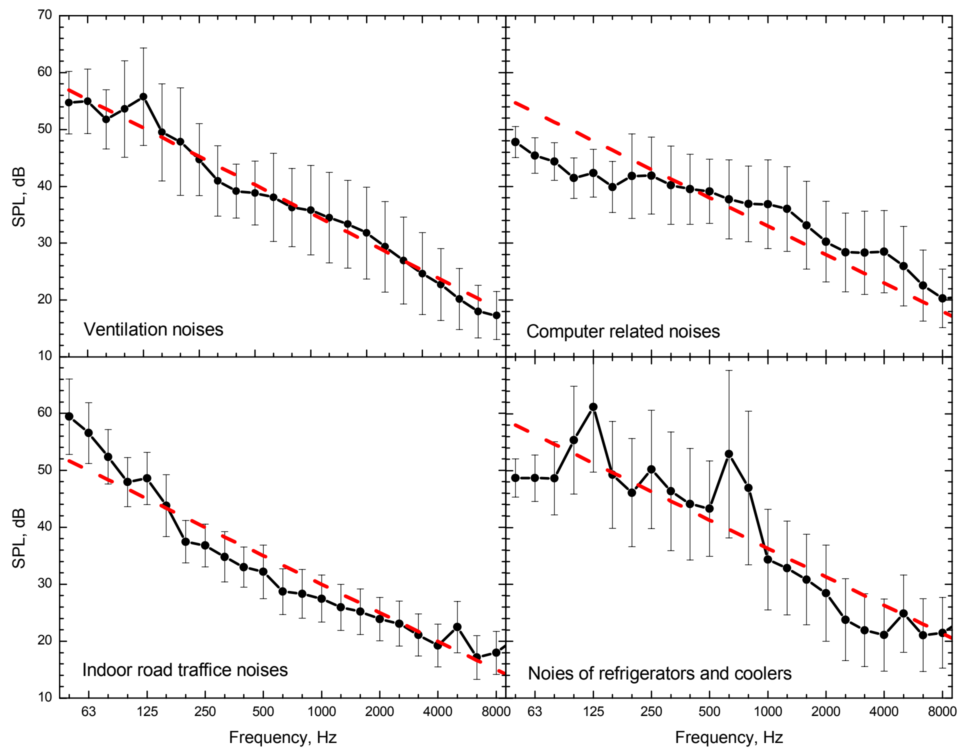

Figure 7. Average spectra of four types of commonly occurring ambient noises near meeting rooms. The vertical bars show the standard deviations of the values about the mean for each 1/3 octave band and the dashed line is a –5 dB/octave reference line.

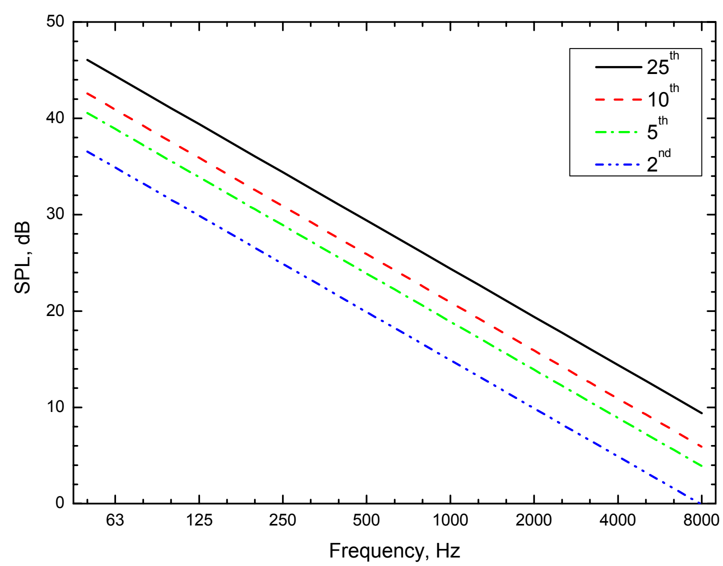

Figure 8. Ambient noise spectra for architectural speech security calculations corresponding to the 2nd, 5th, 10th and 25th percentile of the measured ambient noise levels during the early evening period.

Prediction of Transmitted Speech Levels

Sound transmission between pairs of adjacent rooms is normally considered in terms of room average sound levels in each room and by assuming diffuse sound fields exist in both rooms. If L_s is the room average level in the source room and L_r the room average level in the receiving room, then

$$L_r = L_s - TL + 10 \log (S/A), \text{ dB} \quad (1)$$

Where *TL*, is the sound transmission loss of the room boundary, *S* is the area of the common elements of the boundaries of the two rooms (walls, doors, etc.), and *A* is the total sound absorption in the receiving room in m^2. However, this does not correspond to the speech security problem.

The talker could be anywhere in the source room and hence a room average source level seems appropriate. However, an eavesdropper is not likely to stand in the middle of the receiving space, but would more likely move close to the common wall between the rooms to obtain higher transmitted speech levels. We would therefore like to predict the transmitted speech level close to the common wall and not in the middle of the receiving room. A distance of 0.25 m from the wall was chosen as close enough to minimize effects of the reverberant sound of the receiving space. Another reason for wanting to predict transmitted speech levels close to the common wall, is that equation (1) only applies to reasonably diffuse spaces and the receiving space could be anything from a small closet to a very large hall or other public space. It would be difficulty to accurately estimated expected room average levels in such spaces.

The transmitted speech levels, $L_{0.25}$, measured at points 0.25 m from the common wall in the receiving space can be estimated as follows,

$$L_{0.25} = L_s - TL + k, \text{ dB} \quad (2)$$

Although some texts suggest that *k* should be – 3 dB [4], initial empirical results suggest a value of +1 dB. Figure 9 plots measured and predicted values of $L_{0.25}$ obtained in a standard sound transmission loss suite consisting of two reverberation chambers. After measuring the sound transmission loss of the wall in the normal manner, absorption was added to the receiving space to simulate more typical conditions in office buildings and $L_{0.25}$ values were measured. The directly measured and predicted $L_{0.25}$ values using equation (2) with k=+1, are compared in Figure 9. Further tests are planned to confirm the success of this method for predicting transmitted speech levels at points close to the wall in the spaces adjacent to meeting rooms.

Measurement of Transmitted Speech Levels

There is also a need for a new measurement protocol to define how to measure transmitted speech levels 0.25 m from the common room boundary element in the receiving space. The measurement protocol should indicate the expected accuracy of the measurement results. The parameters that would influence the accuracy of the measurement results would include: the type of test sound source, the number of source positions, and the number of microphone positions used to obtain a room average source room levels. The protocol must also specify how the levels 0.25 m from the room boundary in the receiving space are to be measured. Extensive sound propagation measurements from 11 meeting rooms have been made to experimentally determine appropriate values of the key measurement parameters for various levels of accuracy and various types of meeting rooms.

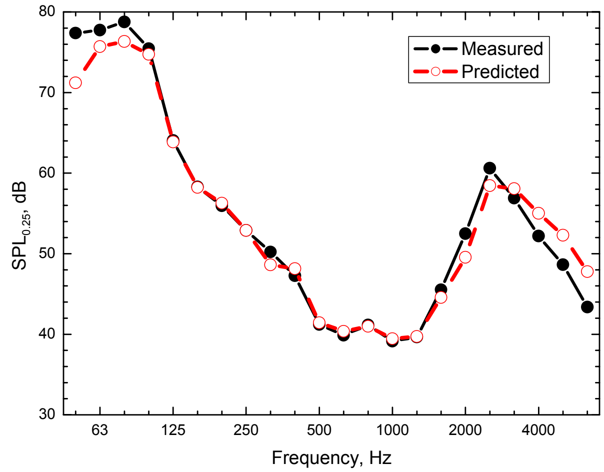

Figure 9. Comparison of directly measured and predicted $L_{0.25}$ values for a typical meeting room wall construction.

Figure 10 illustrates the influence of source directionality on the spatial variation of sound levels in the source room for one example meeting room. Using an approximately omni-directional source (duodecahedron loudspeaker) gives spatial variations that are close to theoretical expectations at lower frequencies [5,6], but systematically increase above theoretical expectations at higher frequencies. However, the use of a conventional, more directional source (20 cm diameter loudspeaker), leads to much larger spatial variations at almost all frequencies. Thus to obtain average source room levels within some tolerance would require more measurement positions using the directional source than using the omni-directional source. Guidelines for the number of measurement positions will be developed from similar measurements in 11 different meeting rooms.

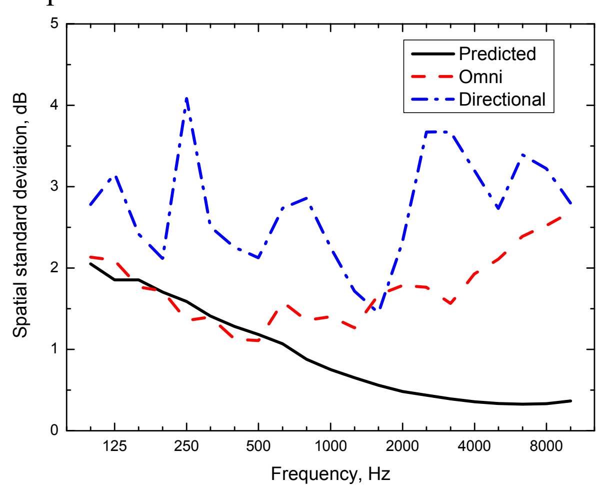

Figure 10. Spatial standard deviations of source room levels using either a directional source (20 cm diameter loudspeaker) or an omni-directional source (duodecahedron loudspeaker).

Of course, any source of uncertainty in the source room levels will also correspond to an uncertainty in the levels measured in the adjacent receiving space. There can also be differences in the transmitted sound levels related to the directionality of the test sound source. Figure 11 shows measured attenuations from room average source room levels to receiving space levels measured at various points 0.25 m from the common wall. The measured receiving space levels vary from point to point along the wall and increase where there is a door or some other weak point. The two types of sound source lead to differences in the measured attenuations. Most, but not all of the measured attenuation values are similar to the difference in room average values that is also shown in this figure. The different results for the two types of source seem much larger when they are expressed in terms of the expected speech intelligibility as shown in the lower half of Figure 11. (The following section describes how speech intelligibility was related to the measured attenuations).

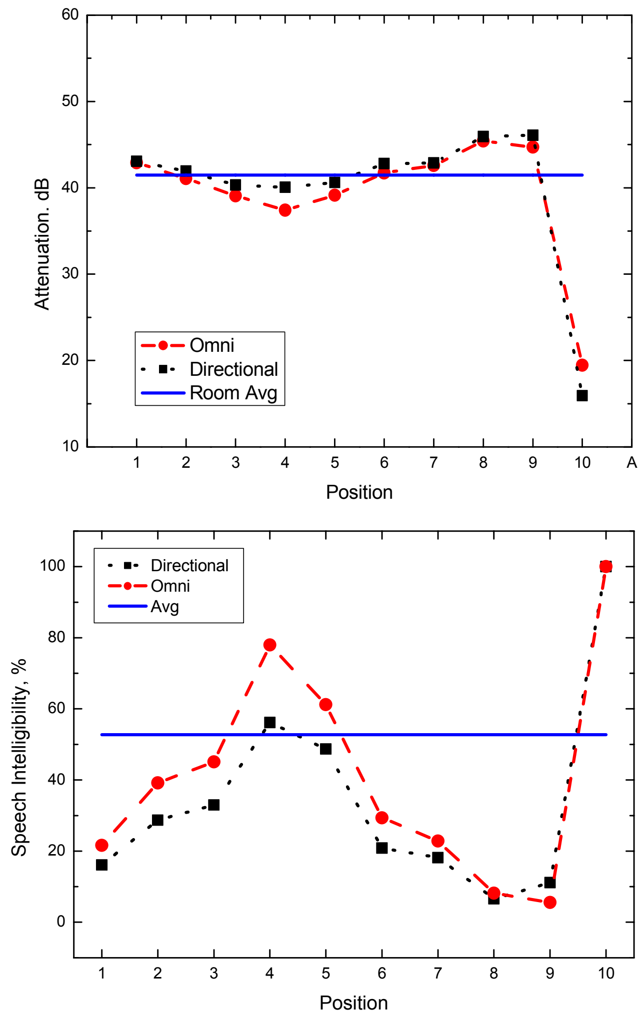

Figure 11. Measured attenuations from the room average levels in the source room to positions in the receiving space located 0.25 m from the common wall using either an omni-directional or a directional sound sources (Upper) and the predicted speech intelligibility for these same attenuations (Lower).

A New Measure of Speech Security

After the transmitted speech levels and the ambient noise levels are known, as a function of frequency, in spaces adjacent to meeting rooms, it is necessary to decide if the room is speech secure. This can be done by calculating a frequency weighted speech-to-noise ratio measure that can be related to subjective assessments of speech security conditions. This measure is the result of extensive subjective evaluations of combinations of simulated transmitted speech sounds and ambient noise. These tests determined the intelligibility of speech as a function of various speech-to-noise ratio measures and also the thresholds of audibility and intelligibility of the transmitted speech sounds.

Figure 12 shows a section through the test room used for these tests. It was an acoustically dead and sound isolated test chamber with a very low natural ambient noise level (13 dBA). Subjects listened to simulated transmitted speech sounds and simulated ventilation noise through two different loudspeaker systems. It is important to realistically simulate the different spatial effects of the speech and noise signals arriving from different directions. Transmitted speech sounds were presented using the loudspeakers in front of the subject and simulated ventilation sounds arrived from the loudspeakers above the listener.

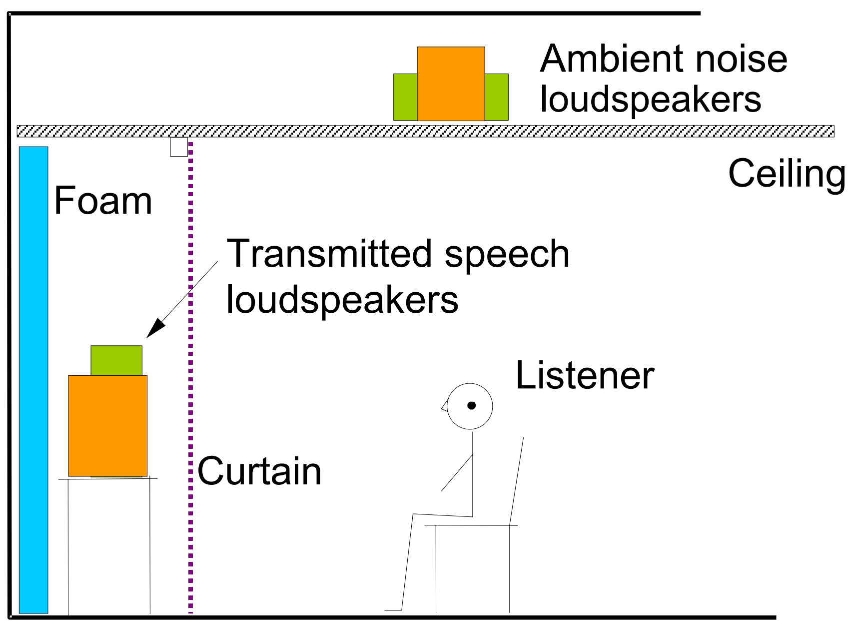

Figure 12. Cross-section through the subjective test chamber showing the location of the listener and the loudspeakers used to reproduce simulated office sounds.

The simulated ambient noises were variations of a –5 dB/octave spectrum with boosted high, mid or low frequencies in some cases, to give a wide range of simulated ventilation noise spectra. The transmitted speech sounds were modified according to the measured sound transmission loss characteristics of 4 different wall types chosen to include quite different variations with frequency of these characteristics.

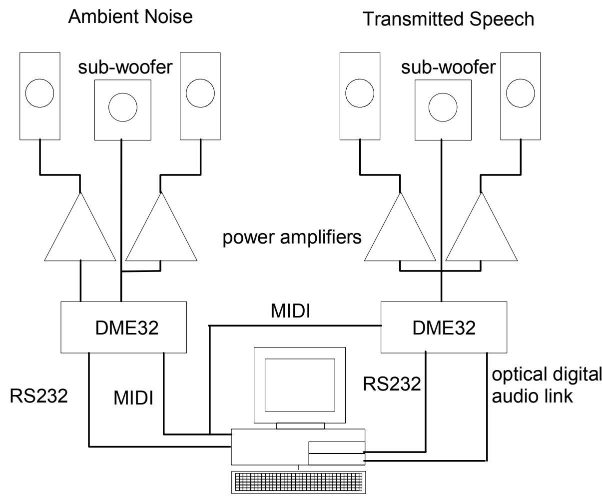

Figure 13. Block diagram of the computer controlled electro-acoustics system used to create simulated speech and noise sounds.

The simulated sound spectra were created using Yamaha Digital Mixing Engines (DME32), which are sophisticated signal processing boxes that can be configured from a controlling computer to produce complex combinations of equalization, delays and reverberation. These can be operated under computer control and Figure 13 shows a block diagram of the associated hardware used to perform these experiments.

Figure 14 shows the spectra of the simulated transmitted speech for the wall types as well as original speech source spectrum. As we would expect, the transmitted speech sounds are much stronger at lower frequencies, making the speech more difficult to understand.

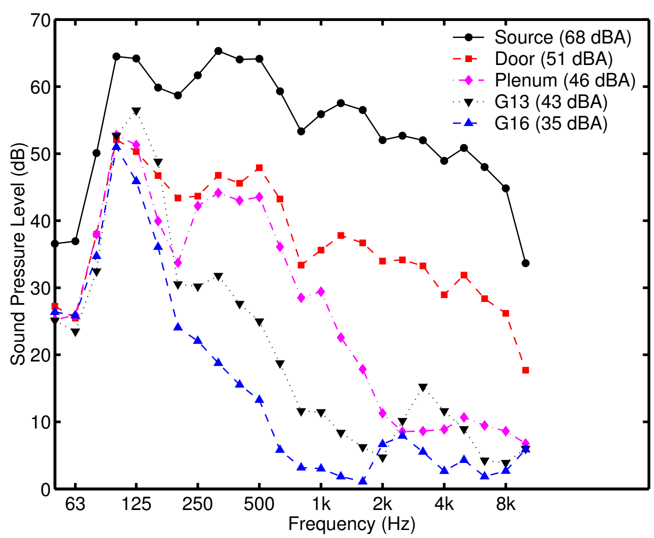

Figure 14 Measured "transmitted" speech spectra.

The speech materials were the phonetically balanced Havard sentences, which are short, low predictability sentences. That is, it is difficult to guess what the second part of the sentence will be from the first part.

In the intelligibility tests, subjects repeated back the words that they thought they had heard and the experimenter recorded the number of correctly identified words. The average percent correct for each combination of speech and noise was the speech intelligibility score. In total, subjects listened to 340 test sentences over 3 different double sessions. These consisted of the combinations of 4 wall transmission loss characteristics, 5 ambient noise spectrum shapes, 3 different speech levels and 8 more cases to create more difficult conditions. Fore each of these 68 cases, the subjects listened to 5 different test sentences to give a total of 340 test sentences that were presented to the subjects in varied random order. Subjects had to be fluent in English and to pass a conventional hearing threshold test as well as a preliminary screening test.

The resulting speech intelligibility scores were plotted versus a number of speech-to-noise time measures. Three of these results are included in Figure 14. In this figure the scatter is a little less than it appears because many points are plotted on top of each other. The Articulation Index (AI) and its newer replacement the Speech Intelligibility Index (SII) are standardize measures, described in ANSI S3.5, intended to be accurate predictors of speech intelligibility scores. In these tests these measures were generally well correlated with intelligibility scores. However, they are not good measures of speech security, because intelligibility is not 0 at an SII value of 0 and the SII and AI measures are not defined below a value of 0. This is illustrated in the middle graph of Figure 14 for SII values. For speech security we would like to assess conditions down to 0 intelligibility and below this in terms of the audibility of the transmitted speech sounds. Therefore SII and AI are not acceptable measures.

Because the frequency weightings in the AI and SII measures have been developed over many years of research, they were incorporated into a new measure, which was simply a SII, weighted signal-to-noise ratio measure. That is, the signal-to-noise ratios in each 1/3 octave band were weighted according to the frequency weightings in the SII standard and then summed to give an overall SII-weighted signal-to-noise ratio. Intelligibility scores are plotted versus this measure in the lower graph of Figure 15. The upper graph of this figure shows intelligibility scores plotted against an A-weighted speech and noise level difference measure that is not as accurately related to intelligibility scores.

In a second experiment subjects were asked to indicate: (a) if they could hear any speech sounds (audibility), then (b) if they could hear the cadence or rhythm of speech sounds, and finally (c) to repeat back any words they had understood. These results were used to indicate the fraction of subjects who: (a) found speech sounds audible, (b) heard the cadence of speech sounds, and (c) understood at least 1 word. The intent is to use these results to define the related thresholds of audibility, of hearing the cadence of the speech and of the intelligibility of the transmitted speech sounds. The subjects again listened to a wide range of combinations of transmitted speech sounds and simulated ambient noises. In this experiment these combinations extended down to conditions where no subject was expected to hear any speech sounds at all.

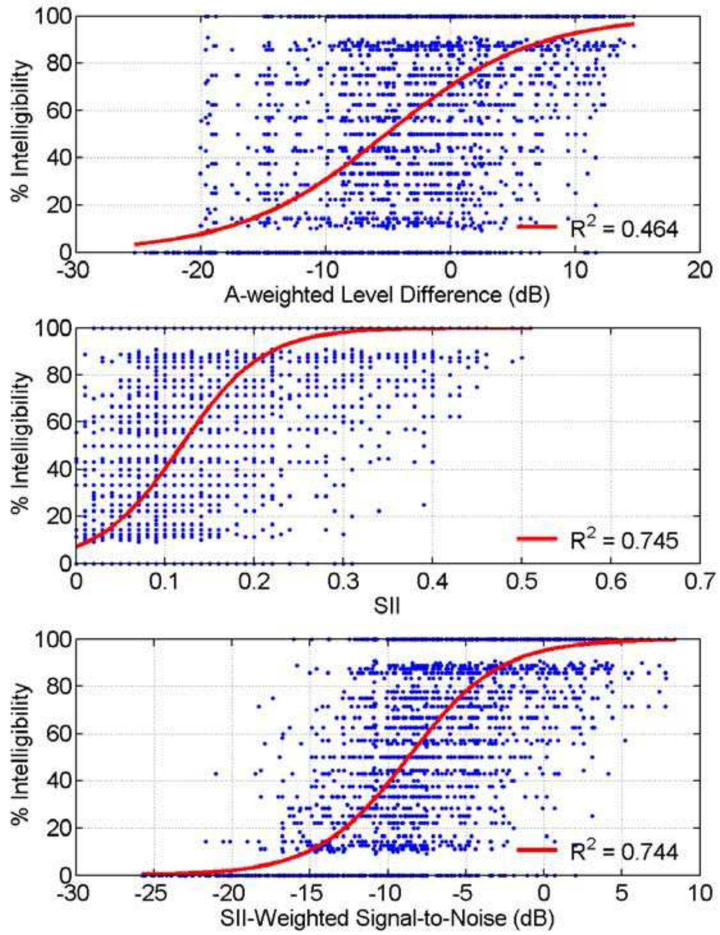

Figure 15. Speech intelligibility scores plotted versus, A-weighted speech and noise level differences (Top), SII (middle, and SII weighted signal-to-noise rations (Bottom).

Figure 16 shows some of the results of this experiment and includes plots of the percentage of subjects above each threshold versus the SII weighted signal-to-noise ratio. The percentages of subjects understanding at least one word (threshold of intelligibility) are quite well related to the SII weighted signal-to-noise ratio measure. The lower two plots in this figure show how the thresholds of cadence and of audibility vary with the value of the SII weighted signal-to-noise ratio. The results extend down to conditions where most subjects could not hear any indication of speech sounds (speech not audible). Because the listeners were all very good listeners with excellent hearing, these results are intended to provide safe conservative estimates of the three thresholds of speech security.

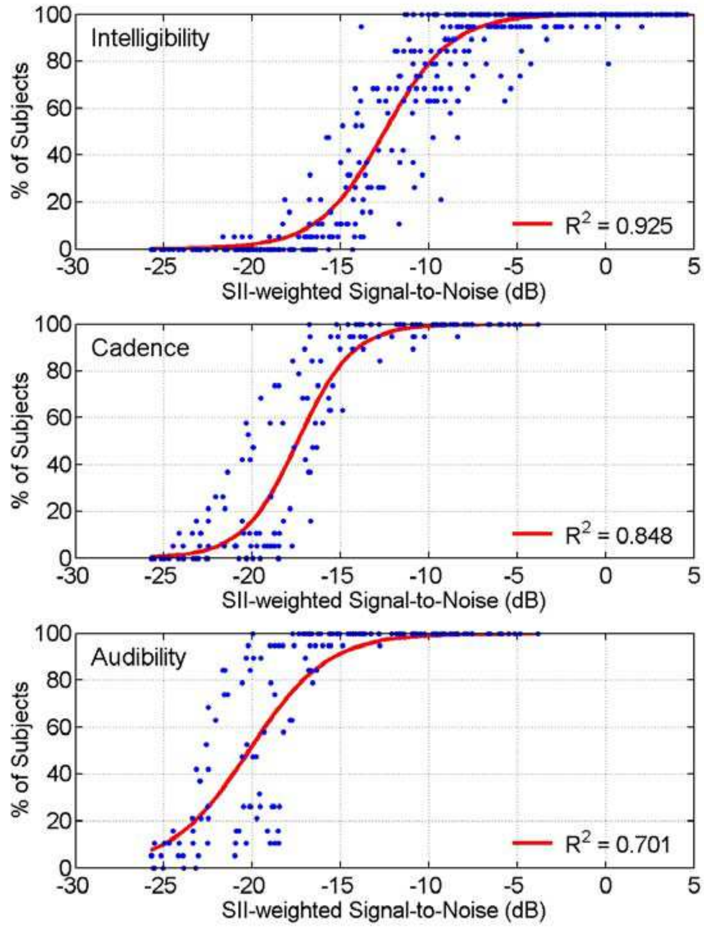

Figure 16. Plots of the percentage of subjects indicating that some speech sound is audible (Bottom), that they can hear the cadence or rhythm of the speech (Middle) and that they can understand at least one word (Top).

To use these threshold curves in the design and evaluation of speech security, the concept of a *just noticeable threshold* is introduced. In psychoacoustics a just noticeable difference is often defined as the difference in two sounds that is detectable by 50% of the listeners in a carefully controlled test. Similarly, the concept of a *just noticeable threshold* would be the point at which 50% of the listeners in a carefully controlled test can detect that a sound is audible or intelligible in some way. Thus from Figure 16 we can see that the *just noticeable thresholds* correspond to SII weighted signal-noise-ratios of: -12.5 dB for intelligibility, -17 dB for the threshold of cadence and -20 dB for the threshold of audibility.

For the thresholds of audibility and of cadence, subjective ratings were found to be a little more strongly related to loudness related measures including a simple difference of A-weighted speech and noise levels. However, the SII weighted signal-to-noise ratio measure is used here as a better measure of all aspects of speech security including the critical question of the intelligibility of the transmitted speech. Ongoing analyses may conclude that a different measure is preferred.

Putting It All Together

This final section attempts to bring the various parts of the work together to illustrate how one might design for various levels of speech security. The results here should be considered as tentative because all of the work on the various contributing components described above is not yet complete and some of the details presented here will probably change. However, the basic concepts are expected to remain as described here.

We would like to estimate the expected degree of speech security by predicting the expected SII weighted signal-to-noise ratio for a particular situation. To do this we need to know the expected speech and noise levels and the degree of security required. We can estimate the probability of a particular speech level from the results in Figure 4. Combining this with the spectral characteristics of the speech (Figure 5) and the effective sound transmission loss of the room boundary, we can estimate the characteristics of the transmitted speech sounds. From Figure 6 we can estimate the probability of particular ambient noise levels in spaces adjacent to meeting rooms and they can be assumed to have a –5 dB/octave spectrum shape. From these speech and noise characteristics we can calculate an SII-weighted signal-to-noise ratio and determine the degree of security from the plots of Figure 15.

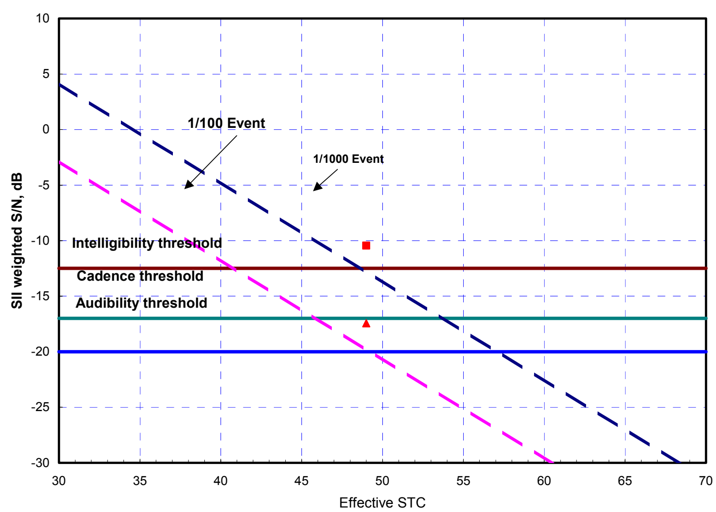

Figure 17. Concept of initial design chart illustrating the required effective STC value to meet various speech security criteria in terms of just noticeable threshold values.

To produce a simple procedure for initial estimates of speech security, SII weighted signal-to-noise ratios were related to the STC ratings of 250 different walls. The SII weighted signal-to-noise ratios were calculated from the measured sound transmission loss of the walls using particular design values of speech and noise levels. Figure 17 illustrates some initial results of this process. In this plot calculation results are give for two combinations of speech and ambient noise levels. One corresponded to a combination of speech and noise levels that would occur in 1/100 of the 10 s intervals (66.7 dBA speech source room level and 31 dBA ambient noise) and the other that would occur in 1/1000 of the 10 s intervals (68 dBA speech source room level and 29 dBA ambient noise). The 1/100 probability event corresponds to a 10 s Leq value that would occur once in 17 minutes on average. The 1/1000 probability event would occur once in about 3 hours. Choosing this latter probability of event would suggest that this combination of speech and noise levels would occur no more than once during most meetings and hence would be a quite safe level of speech security.

The dashed diagonal lines indicate the mean trends of the calculated SII weighted signal-to noise ratios as a function of the wall STC value. The horizontal lines indicate the three *just noticeable threshold* values. The user can decide which threshold is an appropriate goal for each design case.

Summary

This project has determined statistical descriptions of speech levels in meeting rooms and ambient noise levels in spaces near meeting rooms. Although large numbers of conditions were measured to obtain these statistical results, they may only be representative of speech levels in Canadian meetings and of noise levels in Canadian buildings. That is, ambient noise levels could vary significantly depending on the details of ventilation systems and even building construction styles. There may even be cultural differences in the speech levels that occur during meetings.

The new subjective results give very good information on which to base criteria for speech security of offices and meeting rooms. The *just noticeable threshold* values are defined as the signal-to-noise ratio at which 50% of the subjects found speech sounds to be audible or intelligible. Three different thresholds were determined, described as the threshold of audibility, the threshold of hearing the cadence of the speech, and the threshold of intelligibility.

New measurement and prediction procedures are proposed to assess or predict the levels of transmitted speech sounds at points 0.25 m from the common wall in the receiving space. By combining the speech levels at these points with the ambient noise levels at the same locations, we can now estimate the degree of speech security in terms of the thresold of audibility or intelligibility.

References

1. Olsen, W.O., “Average Speech Levels and Spectra in Various Speaking/Listening Conditions: A Summary of the Pearsons, Bennett, and Fidell (1977) Report”, Journal of Audiology, vol. 7, 1-5 (October 1998).
2. Hoth, D.F., “Room Noise Spectra at Subscribers’ Telephone Locations”, J. Acoust. Soc. Am., vol. 12, 449-504 (1941).
3. Blazier, W.E., “Revised Noise Criteria for Application in the Acoustical Design and Rating of HVAC Systems”, Noise Control Engineering Journal, 16(2), 64-73, (1981).
4. Pierce, A., “Acoustics”, p. 279, published by Acoustical Society of America (1991).
5. Lubman, D., “Precision of Reverberant Sound Power Measurements”, J. Acoust. Soc. Am., vol. 56, 523-533 (1974).
6. Chu, W.T., “Precision of Sound pressure Level Measurements in a Reverberation Chamber”, Building Research Note No. 101, National Research Council, Canada (1975).