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**Publisher's version / Version de l'éditeur:**
https://doi.org/10.1121/1.3277220
*Journal of Acoustical Society of America, 127, 2, pp. 815-822, 2010-02-01*

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**NRCC-54471**

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July 2011

A version of this document is published in / Une version de ce document se trouve dans:
*Journal of Acoustical Society of America,* 127, (2), pp. 815-822, February-01-10
DOI: 10.1121/1.3277220

# Speech Levels in Meeting Rooms and the Probability of Speech Privacy Problems

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Shortened Title: Speech levels and speech privacy

PACS number: 43.55.Hy

Date uploaded: _19 August 2009_

Revised: _24 November 2009_

## Abstract

Speech levels were measured in a large number of meetings and meeting rooms to better understand their influence on the speech privacy of closed meeting rooms. The effects of room size and number of occupants on average speech levels, for meetings with and without sound amplification, were investigated. The characteristics of the statistical variations of speech levels were determined in terms of speech levels measured over 10 s intervals at locations inside, but near the periphery of the meeting rooms. A procedure for predicting the probability of speech being audible or intelligible at points outside meeting rooms is proposed. It is based on the statistics of meeting room speech levels, in combination with the sound insulation characteristics of the room and the ambient noise levels at locations outside the room.

## Introduction

It is sometimes required that speech from a meeting room be unintelligible or even inaudible to an eavesdropper outside the room. When this is achieved we can describe the room as having a certain degree of speech privacy, and when the degree of privacy is adequate, we can say that the room is speech secure. When speech from the room is intelligible or audible outside the room, we can say there has been a speech privacy lapse. Whether the speech from the meeting room is intelligible or audible to a particular eavesdropper outside the room will depend on the level of the speech in the room, the sound insulation characteristics of the room boundary, and the level of ambient noise at the location of the eavesdropper outside the room. Of course, speech levels in meeting rooms are not constant but vary from moment to moment. The likelihood of a speech privacy lapse will depend on the probability of louder speech levels occurring.

The average speech levels of children, male and female adult talkers have been determined for varied vocal effort by Pearsons et al. [1]. However, the statistical distribution of speech levels over time in meeting rooms has not previously been investigated. In this new work, the statistical properties of speech levels incident on the boundaries of meeting rooms were determined by measurements in a large number of meetings and meeting rooms.

This paper first investigates the relationships of average meeting room speech levels with meeting room parameters such as room size and number of occupants. Following this, the statistical distributions of speech levels in meeting rooms are presented. The new results form the basis for a new procedure for estimating the likelihood of speech privacy lapses for meeting rooms from the statistical properties of speech levels in meeting rooms. This new procedure is presented in the final sections of this paper.

## I. Procedure

Sound levels in meeting rooms were measured over 24-hour periods using data logging sound level meters located near the periphery of the room. The integrating sound level meters (Brüel and Kjær type 2236) were fitted with external batteries so that they could be left operating unattended for 24-hour periods. The sound level meters stored an energy average A-weighted sound level ($L_{eq}$) for every 10 s interval over the 24-hour period. Four meters were placed in each room and were typically located approximately 1 m from the room boundaries with the microphone 1.2 m above the floor. These locations were chosen so that the recorded speech levels were representative of the sound incident on the walls of the meeting room.

Fig. 1 (a) illustrates an example of measured 10 s $L_{eq}$ values over a 24-hour period. The levels associated with each meeting were identified from records like this one and the known schedule of meetings in the room. Fig. 1 (b) illustrates the 10 s $L_{eq}$ values versus time for one meeting from the 24-hour record in Fig. 1 (a). During the meeting the sequence of 10 s $L_{eq}$ values is seen to vary somewhat randomly. The stored 10 s $L_{eq}$ values for the 4 meters in each meeting were first used to calculate an average $L_{eq}$ for each meeting. The $L_{eq}$ values from the intervals between meetings were used to analyse ambient noise levels in the meeting rooms. These could be compared with $L_{90}$ values (the A-weighted noise level exceeded 90% of the time) that were also measured for each 10 s interval.

Data was obtained for a total of 79 meetings in 32 different meeting rooms. Twenty-nine of the meetings included the use of sound amplification systems. The sound amplification systems were quite simple and most had 1 or 2 loudspeakers located at the front of the room. Two of the 32 rooms were repeats to include measurements of meetings with and without sound amplification in the same rooms. The range of numbers of people present, room volumes and floor areas are listed in Table 1.

## II. Average Speech levels in Meeting Rooms

### (a) Meeting average results

Meeting room average $L_{eq}$ values were calculated for all 10 s $L_{eq}$ values measured in each of the 79 meetings. These meeting average $L_{eq}$ values are summarised in Table 2. As well as the average $L_{eq}$ values, the standard deviations of the 10 s $L_{eq}$ values are given and the number of meetings included in each of the categories of rooms listed. There are small differences of typically 1 or 2 dB between the averages for some categories. These will be discussed in each of the following sections for each variable.

### (b) Effects of room size

The results in Table 2 indicate, that sound levels were on average 2.8 dBA higher in smaller rooms (less than 100 $m^3$) than in larger rooms (greater than 100 $m^3$) for rooms without amplified speech sound. There were no small rooms with sound amplification.

The effect of room size on speech $L_{eq}$ values was investigated by plotting measured room average $L_{eq}$ values versus various parameters describing the rooms and numbers of people present. The variables considered are listed in Table 3. There were very few significant systematic effects of these variables on the room average speech $L_{eq}$

values. However, when the room average $L_{eq}$ values for non-amplified rooms were plotted versus meeting room volume, as shown in Fig. 2, there was a statistically significant ($p<0.001$) decrease in $L_{eq}$ values with increasing room volume. A similar but less significant effect ($p<0.01$) was found when the data were plotted versus meeting room floor area. Significant variations of $L_{eq}$ values with room size were not found for rooms using sound amplification systems. There were also no significant effects of the number or the density of people in the rooms.

Although the regression line in Fig. 2 indicates changes of $L_{eq}$ values by as much as 5 dB with room volume are possible, effects this large are probably not likely for conditions in most meeting rooms. This is partly because the larger rooms included in Fig. 2, with volumes of approximately 500 $m^3$, would usually have sound amplification systems which were found to eliminate the changes in speech levels with room volume.

Speech in smaller rooms (i.e. less than 100 $m^3$) not only had a little higher sound levels but also the sound levels seemed a little more scattered between rooms of similar room volume. This is probably due to the unavoidable problem of some talkers being quite close to the microphones in the smaller rooms, which might influence the slope of the regression line in Fig. 2. This also suggests, that for speech privacy concerns, there may also be higher speech sound levels incident on the room boundaries due to the presence of talkers close to the room boundaries in smaller meeting rooms and hence an increased risk of speech privacy problems at locations outside the room.

**(c) Effects of amplification**

The results in Table 2 indicate that on average, speech levels were 2 dB higher in rooms with sound amplification systems operating. At first this may seem a rather small difference because amplification systems would be expected to have a larger effect. In two of the rooms, meetings were measured in the same room with and without sound amplification. The room average speech $L_{eq}$ values for these two rooms, shown in Table 4, indicate that the amplification systems increased speech levels by an average of 10.8 dB.

The smaller difference between the averages for all amplified and all non-amplified conditions in Table 2 is probably due to the locations of the measurement microphones. They were located around the periphery of the rooms to obtain speech levels representative of the sound incident on the room boundaries. The results in Table 2 seem to indicate that the amplification systems were in general set up to obtain speech levels, at more distant listening positions, similar to the speech levels found in smaller and non-amplified rooms. That is, sound amplification systems do not normally create much higher sound levels than are found in good non-amplified conditions. (This may not be true for much larger rooms such as theatres and auditoria).

**(d) Effects of background noise**

Estimates of the background noise levels in the meeting rooms were obtained using two different approaches. One approach was to use measured $L_{eq}$ values, obtained in each meeting room when they were unoccupied. The second approach used the $L_{90}$ values obtained during the meetings in each room. Both $L_{eq}$ and $L_{90}$ values were energy averages of values for all 10 s intervals during meetings. The average results for all meetings in Table 5 show that the two approaches led to nearly identical results. This confirmed that the $L_{90}$ values measured during the meetings were a good indication of the actual ambient noise levels in the rooms.

The relationship between meeting-average speech levels and ambient noise levels is shown in Fig. 3. This figure shows systematically increasing speech levels with increasing ambient noise levels. For unamplified speech this is a well-known effect (the Lombard Effect [2]) whereby people naturally talk louder to maintain an acceptable signal-to-noise ratio. The results in Fig. 3 indicate this type of effect occurs for all meetings including both amplified and unamplified speech. The diagonal lines on Fig. 3 indicate conditions with signal-to-noise ratios of +10 and +15 dB. A +10 dB signal-to-noise ratio corresponds to reasonably good conditions for speech and a +15 dB signal-to-noise ratio to very good conditions for adults with unimpaired hearing [3].

From the results in Fig. 3 it is evident that it is important to control ambient noise levels in meeting rooms to improve speech privacy. This is true because when ambient noise levels are allowed to increase, speech levels will also increase correspondingly, and the higher speech levels are more likely to be audible or intelligible outside the meeting room. Of course, for good speech intelligibility inside the meeting room, it is also important to have low background noise levels (ideally 35 dBA in a classroom sized rooms [4,5]). That is, reduced ambient noise levels in meeting rooms would improve speech intelligibility in the meeting room and increase speech privacy at locations outside the meeting room.

## III. Statistical Distribution of Speech Levels

Higher speech levels in meeting rooms are more likely to lead to speech privacy problems at positions outside the room. It is therefore important to determine the probability of various higher speech levels occurring in typical meeting rooms. This was done by examining the statistical distribution of the 10 s speech $L_{eq}$ values for all meetings. A total of 110,773 speech $L_{eq}$ values were included. Because the average values in Table 2 indicate a small difference between the amplified and unamplified speech cases, the distributions of 10 s speech $L_{eq}$ values were first considered separately for the two cases as well as for the combined data.

The distributions of 10 s $L_{eq}$ values are shown in Fig. 4 plotted as cumulative probability distributions. There are small differences as expected between the amplified and unamplified cases and the differences vary a little with speech level. However, it was decided that because the values of the combined data distribution were usually within 1 dB of the separate amplified and unamplified speech distributions, the combined data could be used to closely approximate conditions in all meeting rooms. The combined distribution was then used to determine the likelihood of speech privacy lapses for all meeting rooms. Fig. 5 plots the cumulative probability distribution of the combined data with expanded scales to make it possible to read off probabilities of the higher speech levels occurring.

From the probabilities of the occurrence of speech levels in Fig. 4 and 5, one can calculate the corresponding average time interval between occurrences of particular higher sound levels taking into account the 10 s duration of each $L_{eq}$ measurement of speech levels. Each probability indicates the frequency of occurrence of all speech levels up to and including the corresponding speech level on the x-axis. For example, a 90% probability corresponds to a speech level of 64.5 dBA, indicating that 90% of the time 10 s speech $L_{eq}$ values would be no higher than 64.5 dBA. Hence, 10% of the time this speech level would be exceeded. There are 360 intervals of 10 s duration in one hour and this would correspond to speech levels exceeding 64.5 dB in 36 of them. On average there would be a 1.67 minute interval between times when this speech level is exceeded. Table 6 shows the results of the calculations of the average interval between occurrences of a range of speech levels from the frequency of occurrence of each speech level. Fig. 5 also includes horizontal dashed lines to indicate the speech levels corresponding to several intervals (1/minute to 1/week).

## IV. Probability of Speech Privacy Problems

The audibility and intelligibility of transmitted speech sounds are related to the signal-to-noise ratio of the transmitted speech and the ambient noise at the listener's position outside the room. Previous research has identified the uniformly-weighted frequency-averaged signal-to-noise ratio to be an accurate predictor of the degree to which speech is intelligible or audible [6]. It is calculated from the spectra of the transmitted speech and of the background noise signals at the listener's position as given by the following,

$$SNR_{UNI32} = \frac{1}{16}\sum_{f=160}^{5000}[L_{ts}(f) - L_n(f)]_{-32}\text{ , dB} \qquad (1)$$

where in each of the 16 $^1/_3$-octave bands centered at frequency $f$ from 160 to 5000 Hz, $L_{ts}(f)$ is the level of the transmitted speech at the listener's position outside the room, $L_n(f)$ is the level of the background noise at the same position, and the subscript '-32' indicates that the quantity in square brackets (i.e. the signal-to-noise ratio in each band) is to be limited to a minimum of -32 dB.

A condition where 50% of attentive listeners could just understand some speech was defined as the threshold of intelligibility [6]. This corresponds to a particular value of $SNR_{UNI32}$. In laboratory experiments this value was –16 dB, but in moderately reverberant conditions with ideally diffuse noise was –11 dB, varying about ±1 dB with variations in reverberation time above 0.5s [7]. At a lower signal-to-noise condition, there is a point where, for 50% of attentive listeners, speech sounds were just audible. This was defined as the threshold of audibility, and corresponds to a higher degree of privacy. The threshold of audibility corresponds to a $SNR_{UNI32}$ value of –22 dB (in both laboratory and real room conditions) [6,7].

To apply $SNR_{UNI32}$ for the assessment of closed room speech privacy, it is necessary to determine the transmitted speech levels and the background noise levels at the listener position. For a given speech level inside the room, the level of transmitted speech depends on the sound insulation provided by the building structure. The relevant measure of sound insulation is the difference in sound level between the average level of a uniform test sound field inside the room and the received level at a spot listener location outside the room [8]. If the average level of the uniform field in the room is $L_s(f)$ and the corresponding received level outside the room is $L_r(f)$, then the level difference in each frequency band is $LD(f) = L_s(f) - L_r(f)$. A uniform field is measured inside the room to represent the average of talkers, who could be located anywhere in the room. The spot receiver locations outside the room are usually chosen to be 0.25 m from the boundaries of the room to minimize the effect of the receiving space, to more realistically represent the locations of potential eavesdroppers, and to allow evaluation of variations of sound insulation, such as due to doors or ducts.

Since the level of speech varies from moment to moment, the speech levels in the room can be assessed statistically. The previous sections of this paper reported new measurements of speech levels $L_{sp}(f)$ in a large number of meetings, and the probability of occurrence of particular levels. The level of the background noise $L_n(f)$ can be measured at the receiver positions outside the meeting room.

In terms of measurable quantities, $SNR_{UNI32}$ outside the room is given by

$$SNR_{UNI32} = \frac{1}{16}\sum_{f=160}^{5000}[L_{sp}(f) - LD(f) - L_n(f)]_{-32}\ , \qquad (2)$$

where $L_{sp}(f)$ is the speech level inside the room, $LD(f)$ is the measured level difference between the average level inside the room and the level at a listener position, and $L_n(f)$, is the background noise at the listener position. Frequently the –32 dB limitation has minimal effect, and Eq. (2) can be simplified to,

$$SNR_{UNI32} = L_{sp}(avg) - LD(avg) - L_n(avg)\ , \qquad (3)$$

where *(avg)* indicates the arithmetic average of $L_{sp}(f)$, $LD(f)$, and $L_n(f)$ over the 16 $^{1}/_{3}$-octave bands from 160 to 5000 Hz.

A particular speech privacy criterion such as the threshold of intelligibility corresponds to a particular value of $SNR_{UNI32}$, such as $SNR_{UNI32,0}$. Rewriting Eq. (3) as an inequality, when the following is true of the speech level,

$$L_{sp}(avg) \leq SNR_{UNI32,0} + LD(avg) + L_n(avg)\ , \qquad (4)$$

then the condition at the listening point is at least as private as the criterion condition, $SNR_{UNI32,0}$. For example, if $\mathrm{SNR}_{\mathrm{UNI32,0}}$ = -16 dB, conditions would be equal to or below the threshold of intelligibility. The quantities $LD(avg)$ and $L_n(avg)$ are properties of the closed room, and Eq. (4) dictates the maximum source room speech level $L_{sp}(avg)$ for which the conditions are adequately private relative to the selected criterion. From the statistics of speech levels, this can be used to determine the interval of time between expected privacy 'lapses', which would correspond to instances for which the speech level is larger than that allowed by Eq. (4).

The privacy criterion is usually chosen as the threshold of intelligibility, and consequently the criterion value of -16 dB is used. Although higher intelligibility threshold values were found in more reverberant and highly diffuse environments, this lower value was judged to be a better estimate of worst case conditions in typical office buildings. Using this value Eq. (4) yields the following relationship,

$$LD(avg) + L_n(avg) \geq L_{sp}(avg) + 16 , \tag{5}$$

which determines the maximum speech level for which conditions at the listening point remain at or below the threshold of intelligibility. The likelihood of this speech level being exceeded is the likelihood that the conditions at the listening point will be above the threshold of intelligibility.

## V. Speech Privacy Class

As previously noted, the quantities $LD(avg)$ and $L_n(avg)$ are properties of the building containing the closed room. The sum of these two terms governs the speech privacy rating of a room, and is called the Speech Privacy Class, *SPC,*

$$SPC = LD(avg) + L_n(avg) . \tag{6}$$

For the threshold of intelligibility criterion, equation (5) indicates that the probability of intelligible transmitted speech occurring for a particular *SPC* value can be determined from the probability of a particular related speech level occurring. By replacing the criterion $SNR_{UNI32,0}$ value with a value of –22 dB, the results would indicate the probability of the threshold of audibility being exceeded.

The probabilities of various speech levels are given in Fig. 4 and 5 but are in terms of A-weighted speech levels. To convert the speech levels to frequency averages in the form of $L_{sp}(avg)$ values, Pearsons' [1] speech spectra were used. Pearsons' 'raised voice' level spectra for male and female talkers were averaged to obtain a representative spectrum shape for meeting room speech. Pearsons' 'raised voice' level spectra were selected because the overall A-weighted levels of these spectra are similar to the average speech level recorded in the 79 meetings that were measured (see Table 2). For this raised speech spectrum, the frequency average speech level $L_{sp}(avg)$ was 12.2 dB less than the A-weighted level of the same spectrum. This was used to convert A-weighted speech levels to frequency averaged speech levels, $L_{sp}(avg)$. It was then possible to determine the probabilities of the occurrence of $L_{sp}(avg)$ values required to determine the probabilities of the related *SPC* values occurring.

For *SPC* values in 5 point steps, the related $L_{sp}(avg)$ values were used to determine the probability of speech privacy lapses. This was done in terms of the threshold of intelligibility being exceeded and for the threshold of audibility being exceeded. The results of these calculations are given in terms of the average time intervals between speech privacy lapses in Table 7.

Using equation (6), the *SPC* values can be related to combinations of ambient noise level at the listener position, $L_n(avg)$, and the measured level difference, $LD(avg)$. Some examples are included in Table 8 for the *SPC* values used in Table 7. In this case, approximately equivalent A-weighted noise levels, $L_n(A)$, to the average noise levels,

$L_n(avg)$, were determined to provide comparable more familiar values. This was done by determining the difference between $L_n(avg)$ and $L_n(A)$ values for a –5 dB per octave spectrum shape, which is representative of indoor ambient noises [9,10]. This resulted in an adjustment of +10.7 dB to $L_n(avg)$ values to approximate equivalent A-weighted levels.

The combination of the information in Table 7 and 8 can be used to estimate the probability of speech privacy lapses for meeting rooms where the ambient noise levels outside the room, $L_n(avg)$, and the transmission characteristics from the room, *LD(avg)*, have been determined.

## VI. Effects of Other Variables and Sources of Error

A number of other factors could influence the speech privacy of meeting rooms or be potential sources of error in the prediction of the expected speech privacy. In particular situations, it may be desirable to include some estimate of their effects.

### (a) Other variables influencing speech privacy

The criterion value $SNR_{UNI32,0}$ for the threshold of intelligibility was determined to be -16 dB in approximately free field conditions with spatially separated speech and noise sources [6], and -11 dB in conditions with ideally diffuse noise and reverberation times of approximately 0.8 s [7]. Differences in meeting room reverberation time and the spatial separation of speech and noise sources could influence the choice of $SNR_{UNI32,0}$ value for the threshold of intelligibility. However, there is no evidence that these effects influence the threshold of audibility.

Speech levels at positions outside the meeting room are determined from measured level differences between the source room average level and the level at each receiver position. Although the source room average level usefully represents the average of all possible locations of talkers in the meeting room, and provides more repeatable results, some locations might lead to higher transmitted speech levels and hence to reduced speech privacy. This is most likely for talker positions close to the meeting room boundary and this is most likely to be a problem in smaller rooms. (The 4 points to the upper left of Fig. 2 may illustrate this phenomenon).

Although a talker located close to the room boundary in the meeting room might be expected to lead to higher incident speech levels, such a talker would most likely be directing their voice towards other occupants in the middle of the room and not towards the room boundary. The effects of the directionality of the talker's voice might lead to a larger reduction in incident levels than the increased incident levels due to the proximity of the talker to the room boundaries. It is not clear how much such a talker location would modify the speech privacy of the room, but the effects would also depend on how reverberant conditions in the meeting room were.

Some listeners are better able to understand speech in noise than others. Their listening abilities would be influenced by their hearing sensitivity and their familiarity with the language being spoken. The listening test results used to determine the thresholds of audibility and intelligibility were based on the condition for which 50% of the listeners with better than average hearing sensitivity could just hear or just understand the transmitted speech. A significant portion of listeners would be able to hear or understand speech at transmitted speech levels several decibels lower. Such more skilled than average listeners would pose a little higher risk of speech privacy lapses.

To account for such better than average listeners, the threshold of intelligibility and audibility could be set at a lower percentage of listeners being able to hear or understand transmitted speech than 50%. This would provide a reduced risk of speech privacy problems, but would probably lead to more expensive constructions.

The calculations assumed knowledge of an average noise level at the listener position. Typical ambient noises can be expected to vary in level over time. Intermittent increases in ambient noise levels due to various transient sources are likely but would not be a problem because they would only result in increases in speech privacy. Transient reductions in ambient noise levels seem much less likely to occur and hence fluctuating noise levels are not expected to be a significant problem.

**(b) Possible sources of error**

There are always possible errors associated with measurements of sound levels. There could be errors associated with the measured speech levels used to describe the statistical properties of speech levels in meeting rooms. However, with such a large number of measurements with many different independent calibrations of equipment, it is expected that the possible small errors would tend to average out. Measurements of ambient noise levels and level differences for particular meeting rooms could also be a source of errors. The ASTM E2638 standard [8] discusses the accuracy of *LD(avg)* measurements.

There are also possible errors in approximate conversions between measures. For example, the measured speech levels were in terms of A-weighted levels, $L_{sp}(A)$, which were converted to corresponding $L_{sp}(avg)$ values. The Pearsons' speech spectra used to determine the appropriate conversion are for speech levels close to the talker and would not exactly represent speech spectra at more distant locations in each meeting room. The possible errors would be expected to vary from room to room and are not easily estimated accurately.

Similar conversions from $L_n(avg)$ to $L_n(A)$ values were also made and would include similar possible errors. However, these were not a part of the calculations and were only to help readers understand the significance of the $L_n(avg)$ values.

## VII. Conclusions

In meetings using sound amplification systems, average speech levels near the periphery of the room were only 2.0 dBA higher than in rooms without sound amplification. There was a small effect of room size on average speech levels in meeting rooms without sound amplification. However, this effect was not found in meeting rooms using sound amplification systems. Sound amplification systems were found to increase speech levels at more distant locations to more closely equal those in smaller rooms without sound amplification. The decrease in levels with room size for meetings without sound amplification was not concluded to be an important effect, because in the larger meeting rooms, sound amplification systems are normally used. In smaller rooms (<100 $m^3$) average speech levels were more varied because of the higher probability of talkers being closer to the measurement microphones.

Speech levels in rooms, both with and without sound amplification, increased with increasing background noise levels. To maximize speech intelligibility in the meeting room, and speech privacy at points outside the room, it is important to reduce ambient noise levels inside meeting rooms. Averages of 10 s $L_{90}$ values during meetings were found to be a good indication of background noise levels in meeting rooms and indicated similar values to $L_{eq}$ values measured in the unoccupied rooms.

The measurements of 10 s $L_{eq}$ values of sounds in meeting rooms provided a large sample of meeting room speech levels for estimating the probability of particular speech levels being exceeded and the average interval between occurrences of particular speech levels in meeting rooms. Because meetings with and without sound amplification had similar speech levels and room size effects were not usually important, the combined speech data from all meetings were used to estimate speech level statistics in all meeting rooms.

Using the uniformly-weighted frequency-averaged signal-to-noise ratio concept and values of this measure for the thresholds of intelligibility and audibility of transmitted speech, the probability of meeting room speech privacy lapses can be determined. Speech privacy was related to the Speech Privacy Class, *SPC*, which is the sum of the background noise level at a position outside the room, $L_n(avg)$, and the level reduction from room-average levels within the meeting room to this same measurement point outside the room, *LD(avg)*. For any combination of *LD*(avg) and $L_n$(avg) the probability of speech being audible or intelligible at points just outside the room can be estimated. The procedure is applicable for all levels of speech privacy from modest confidentiality to high speech security.

There are a number of special cases that may be less well predicted from these results. These would include smaller rooms with talkers close to the room boundaries and especially so if they are near sound isolation weak spots such as doors. They may also include rooms with teleconferences where participants may, on average, talk louder than in other rooms. These cases were not included in the current study, but could be considered in future investigations.

## Acknowledgments

Funding for this work was provided by Public Works and Government Services Canada (PWGSC) and the Royal Canadian Mounted Police (RCMP).

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## Tables

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

| | |
|---|---|
| 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 2. Meeting-average sound levels ($L_{eq}$, dBA) for various amplified and non-amplified conditions with the standard deviation of each group of N meetings. (* standard deviation of the 10 s $L_{eq}$ values)

| **Condition** | **Meeting-average speech level, $L_{eq}$, 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 3. Variables considered for possible systematic effects on the measured speech levels.

| Quantity | Units |
|---|---|
| Meeting room volume | $m^3$ |
| Meeting room floor area | $m^2$ |
| Volume density of people | Number of people/ $m^3$ |
| Area density of people | Number of people/ $m^2$ |
| Number of people | Number |

Table 4. Meeting-average speech levels measured with and without sound amplification systems in two rooms.

| Room | Non-amplified meeting ($L_{eq}$, dBA) | Amplified meeting ($L_{eq}$, dBA) | Difference ($L_{eq}$, dBA) |
|---|---|---|---|
| Annex (521 $m^3$) | 52.8 | 64.9 | 12.1 |
| Centennial (520 $m^3$) | 52.6 | 61.4 | 8.8 |
| Average | | | 10.8 |

Table 5. Comparison of average ambient noise measurements from daytime $L_{90}$ values (during meetings) and $L_{eq}$ values (between meetings, i.e. no meeting sounds).

| Measure | Mean value | Standard deviation | Number of measurements |
|---|---|---|---|
| $L_{90}$ during meetings | 49.4 | 3.3 | 149 |
| $L_{eq}$ of ambient noise between meetings | 49.3 | 4.5 | 57 |

Table 6. Example results for the calculation of the average time intervals between occurrences of particular speech levels in the meeting room speech data. 'Prob' is the probability of occurrence in percent of a speech level equal to or less than the corresponding speech level in column 1. The next two columns indicate the number of times per hour and per 8 hour work day that the speech level would be exceeded (i.e. the number of 10 s $L_{eq}$ intervals). The last two columns give the average time interval between 10 s $L_{eq}$ values exceeding these levels.

| Speech dBA | Prob, % ≤ | N/hour exceed | N/day exceed | Minutes between | Hours between |
|---|---|---|---|---|---|
| 55 | 40.265 | 215.05 | 1720.4 | 0.28 | 0.0047 |
| 60 | 71.622 | 102.16 | 817.3 | 0.59 | 0.0098 |
| 65 | 91.388 | 31.00 | 248.0 | 1.94 | 0.0323 |
| 70 | 98.540 | 5.25 | 42.0 | 11.42 | 0.1903 |
| 75 | 99.798 | 0.73 | 5.8 | 82.43 | 1.3738 |
| 80 | 99.974 | 0.09 | 0.8 | 636.67 | 10.6112 |

Table 7. Summary of expected average time intervals between intelligibility and audibility lapses for Speech Privacy Class, *SPC*, values from 60 to 90.

| *SPC* | Time between intelligibility lapses | Time between audibility lapses |
|---|---|---|
| 60 | 0.32 min | - |
| 65 | 0.76 min | - |
| 70 | 2.87 min | 0.62 min |
| 75 | 18.03 min | 2.09 min |
| 80 | 2.28 hours | 12.54 min |
| 85 | 15.30 hours | 1.53 hours |
| 90 | - | 11.22 hours |

Table 8. Speech Privacy Class, *SPC*, values for combinations of background noise, $L_n(avg)$, and related *LD(avg)* values.

| | **Very quiet** | **Quiet** | **Moderate noise** |
|---|---|---|---|
| $L_n(A)$, dBA | 25.0 | 35.0 | 45.0 |
| **$L_n(avg)$, dB** | 14.3 | 24.3 | 34.3 |
| ***SPC*** | ***LD(avg)*** | ***LD(avg)*** | ***LD(avg)*** |
| 60 | 45.7 | 35.7 | 25.7 |
| 65 | 50.7 | 40.7 | 30.7 |
| 70 | 55.7 | 45.7 | 35.7 |
| 75 | 60.7 | 50.7 | 40.7 |
| 80 | 65.7 | 55.7 | 45.7 |
| 85 | 70.7 | 60.7 | 50.7 |
| 90 | 75.7 | 65.7 | 55.7 |

## Figure titles

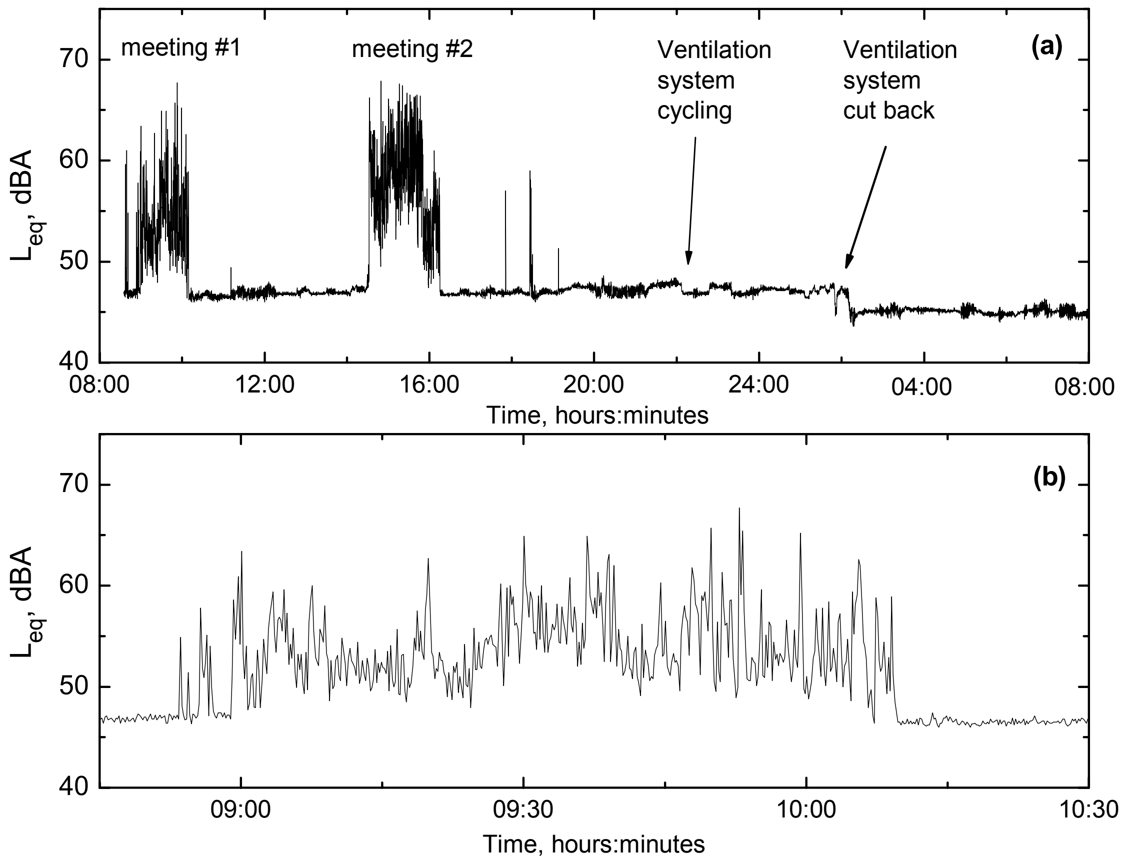
Fig. 1. Recorded time history of 10 s $L_{eq}$ values from one data logger, (a) complete 24-hour period, and (b) enlarged portion for one meeting.

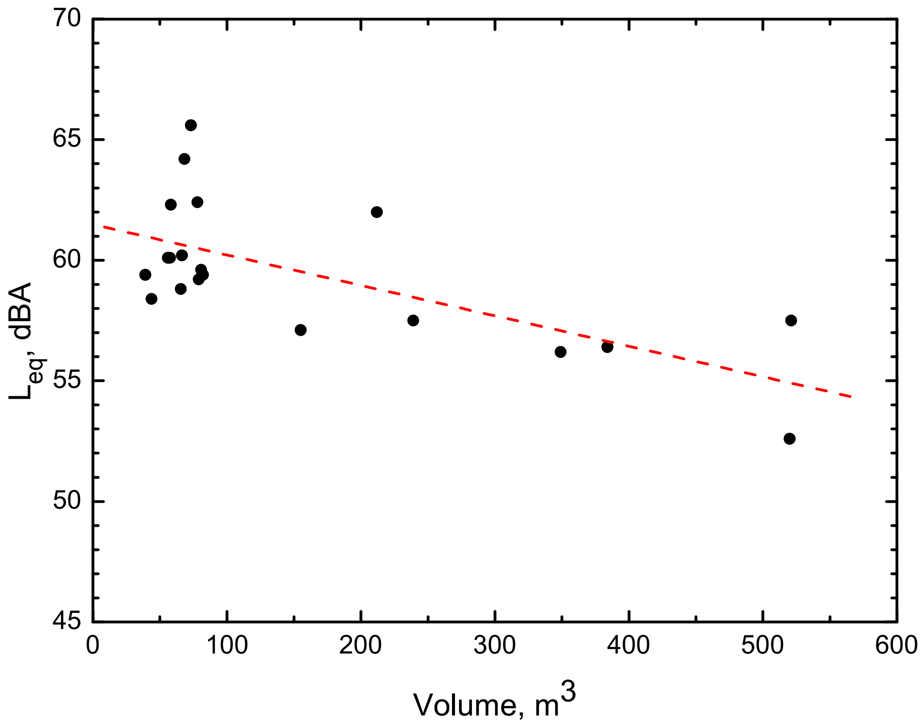
Fig. 2. (Color online) Plot of meeting-average speech $L_{eq}$ values versus meeting room volume and best-fit regression line for meetings without sound amplification systems. ($R^2 = 0.453$, $p < 0.001$).

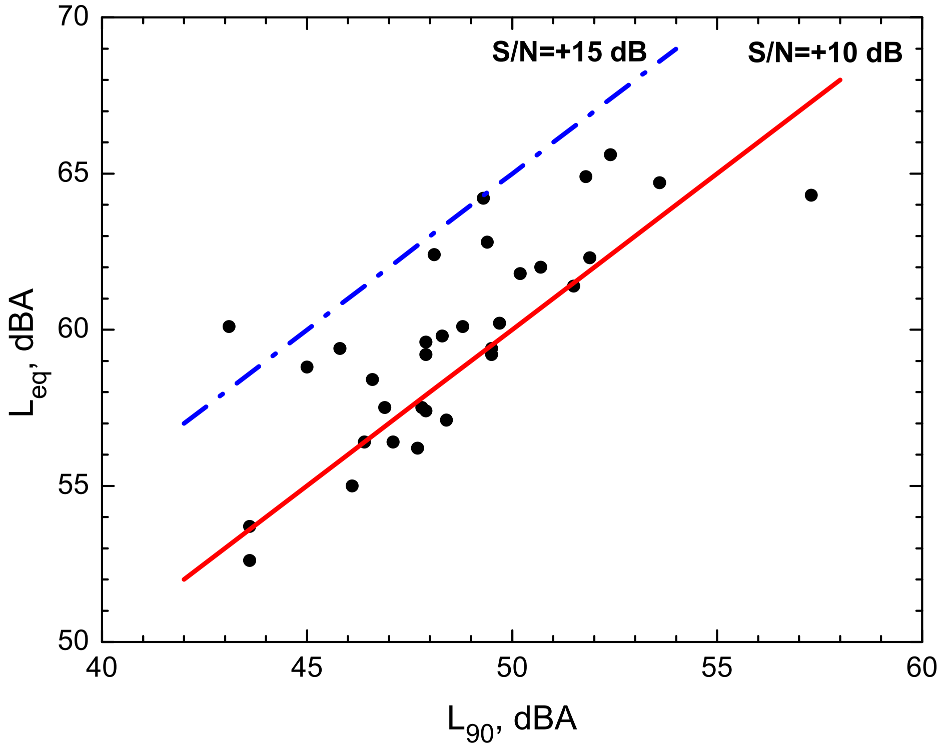
Fig. 3. (Color online) Meeting-average speech levels ($L_{eq}$) versus ambient noise levels in the meeting rooms ($L_{90}$). The solid line shows situations with a +10 dB speech-to-noise ratio (S/N) and the dash-dotted line shows the more ideal case of a +15 dB speech-to-noise ratio.

Fig. 4. (Color online) Cumulative probability distributions of 10 s speech $L_{eq}$ values for: unamplified speech cases, amplified speech cases and the combined data.

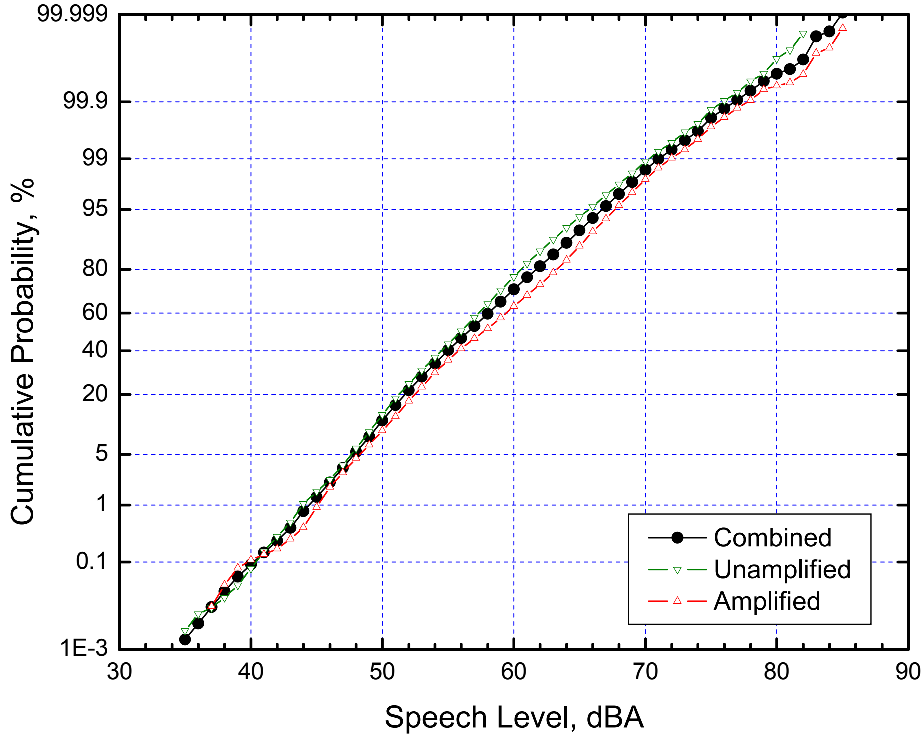
Fig. 5. (Color online) Cumulative probability distributions of 10 s speech $L_{eq}$ values for the combined data with expanded scales to better show the data for higher speech levels. The labels on the horizontal dashed lines (1/minute to 1/week) indicate the equivalent intervals between occurrences of these 10 s speech $L_{eq}$ values.


meeting #1
meeting #2
Ventilation system cycling
Ventilation system cut back
(a)
70
60
50
40
$L_{eq}$, dBA
08:00
12:00
16:00
20:00
24:00
04:00
08:00
Time, hours:minutes
(b)
70
60
50
40
$L_{eq}$, dBA
09:00
09:30
10:00
10:30
Time, hours:minutes

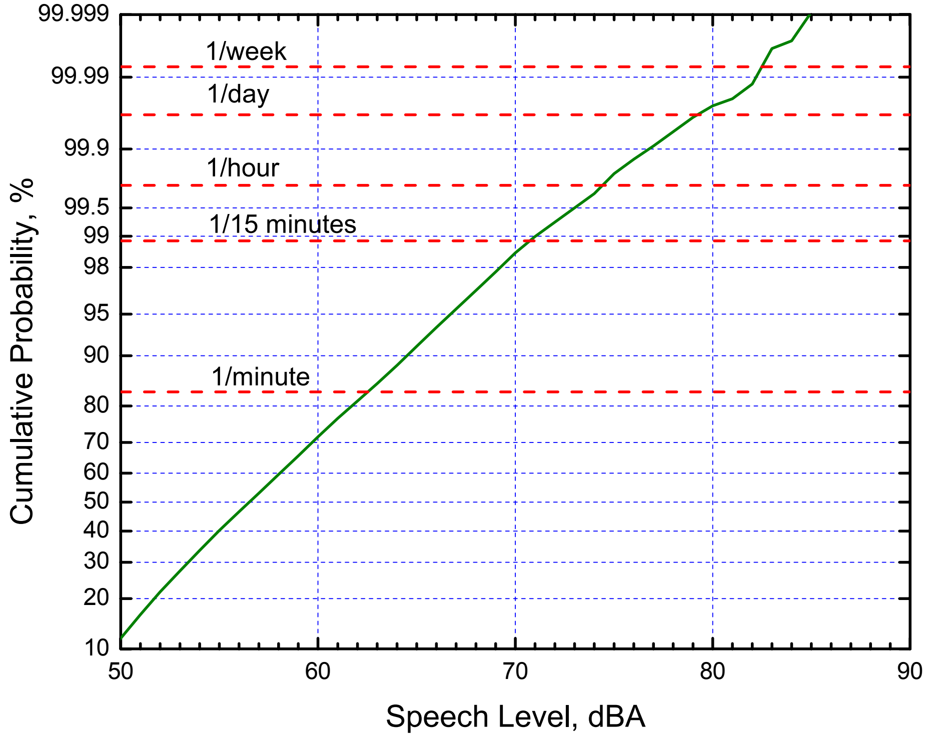

70
65
60
55
50
45
0
100
200
300
400
500
600
$L_{eq}$, dBA
Volume, $m^3$



S/N=+15 dB
S/N=+10 dB
L_eq, dBA
L_90, dBA
70
65
60
55
50
40
45
50
55
60



Cumulative Probability, %
99.999
99.9
99
95
80
60
40
20
5
1
0.1
1E-3
30
40
50
60
70
80
90
Speech Level, dBA
Combined
Unamplified
Amplified


Cumulative Probability, %
Speech Level, dBA
99.999
99.99
99.9
99.5
99
98
95
90
80
70
60
50
40
30
20
10
50
60
70
80
90
1/week
1/day
1/hour
1/15 minutes
1/minute