**Title**

# Acoustical performance measurement protocols for commercial buildings



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## Summary Report January 2012

# Acoustical Performance Measurement Protocols for Commercial Buildings

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### ABSTRACT

A common complaint in work spaces is lack of speech privacy in open plan and private offices. Standard methods exist to quantify speech privacy by measurement and calculation. Performing these methods, although accurate, requires the precision of expensive hardware and the experience of professional acousticians. Robert Young (1965) developed a simple method using common variables to accurately determine speech privacy. These variables can be estimated during design or measured after construction. A side by side evaluation of the standard speech privacy methods were compared to a method based on Young's research. These evaluations determined that the methods had comparative levels of accuracy and the Young method costs substantially less to utilize. The measurements required by all of the evaluated methods were performed within three types of private office and three types of open plan office spaces. Following the testing of the private offices there was a review of the sound isolation of the shared partition and the background noise in the receiving office. Measurements in the open plan spaces were conducted in spaces with different height partitions to identify if this was a factor in the measured speech privacy level. A pink noise signal was used as the source noise for measurement between all of the tested spaces. The pink noise signal was adjusted to have a frequency response similar to a human voice. The constant level of pink noise was produced as a test signal for playback on a compact disc or MP3 player and an appropriate loudspeaker. The appendix summarizes all measurements.

## INTRODUCTION

This study compares four methods to quantify speech privacy in office spaces and assesses their accuracy and cost-effectiveness. A further objective of this study will be to identify what level of accuracy is required from speech privacy testing to achieve useful results so as to reduce the costs of speech privacy measurements. The four methods are:

**PMP.** The Level 2 methodology contained in the "Performance Measurement Protocols for Commercial Buildings" (PMP) document published by ASHRAE/USGBC/CIBSE (ASHRAE/USGBC/CIBSE 2009)

**GSA/ASTM.** The measurement protocol used by the U.S. General Services Administration, contained in ASTM (American Society for Testing and Materials) E1130-08 (ASTM E1130, 2008)

**CBE.** The CBE measurement protocol for predicting speech privacy (Salter et al. 2003)

**Young.** The Young Method protocol for speech privacy calculation (Young, 1965)

The PMP, GSA/ASTM and the CBE method methodologies require sophisticated instrumentation and acoustical experts to conduct the measurements. The Young method uses simple instrumentation and the measurements can be conducted by a trained technician. An evaluation of the benefits and disadvantages of these methods were assessed during measurements in open-plan and enclosed (e.g., private office) spaces. A comparison of each method's data, measurement complexity, accuracy, and estimated measurement costs are presented.

## SECTION 1: PERFORMACE MEASUREMENT PROTOCOL

The PMP provides three levels of acoustical measurements to objectively assess the acoustical qualities of a space. The three levels are described as basic, intermediate, and advanced and correspond to the amount of effort, detail, rigor, accuracy, and cost to achieve the measurement objectives of each level.

- A class 1, as defined in IEC 616721-1 (2002), or type 1, as defined in ANSI S1.43 and ANSI S1.11, sound level meter with parallel octave band filters covering the nine frequency bands from 31.5 Hz to 8 kHz and internal reverberation analysis software
- A type 1 acoustic calibrator
- Annual calibration of sound level meter and calibrator
- Optional – Full-range, powered loudspeaker

The PMP states: "Instrumentation, including the powered loudspeaker, meeting the above requirements will range in cost from $9,000 to $12,000. Alternatively, the measurements can be completed by a third-party consultant. Fees for these services will range from $2,000 to $5,000, depending on the number of occupied spaces and measurements required."

### Background Noise Measurements

The PMP stipulates that background noise measurements should be conducted in spaces where occupants work, such as open-plan offices, private offices, and conference rooms. High background noise levels can cause annoyance and interrupt concentration, which impairs productivity. The purpose of the background noise measurements is to quantify the noise level of HVAC equipment and intruding noise from the exterior, such as vehicular traffic, rail vehicles, and aircraft. The Level 2 guidelines state that at least four background noise measurements should be conducted per space, and one of the measurements should be at the occupants typical position (e.g., at the seated ear height). Each measurement should have a minimum duration of 30 seconds, and measurements should occur in unoccupied spaces with the HVAC system operating (preferably at maximum velocity). Care should be taken to avoid measurement contamination from extraneous noise sources (e.g., people talking, doors closing).

### Reverberation Time Measurements

The PMP states that reverberation time measurement should be conducted in spaces requiring "good speech communication". In general, spaces with large amounts of acoustically reflective surfaces (e.g., glass, concrete, gypsum board) have longer reverberation times than spaces with acoustically absorptive materials (e.g., carpet, acoustical tile). Long reverberation times degrade speech intelligibility and impair communication. The Level 2 guidelines state that reverberation times shall be measured with either an impulsive noise source (e.g., balloon pop or starter gun) or with a powered loudspeaker. As with the background noise measurements, care should be taken to avoid contamination from extraneous noise sources.

### Reporting

After the measurements have been completed and the data analyzed, a measurement test report should be prepared which summarizes the following:

1. Facility location
2. Identification (manufacturer, model number, and serial number) of the acoustic instrumentation used and date of last calibration
3. Name of the person(s) conducting the measurements
4. Date and time of day of each measurement
5. Microphone location for each measurement
6. Definition of whether the measurement microphone was hand-held or mounted on a tripod
7. General description of the room including room name or number, approximate floor area
8. General description of the surface treatments and the room occupancy
9. General description of the HVAC system, including operating conditions and room temperature
10. General description of whether windows or doors are open and origin of any intruding noise.
11. Description of surface treatments of walls, ceiling, and floors; as well as furniture and other materials within the space.
12. Average (Leq) octave band sound pressure levels for each measurement location
13. Measured noise criteria rating for each room.
14. Measured reverberation time (RT60) for each room where the RT60 criteria applies.

The measured data is to be used as a baseline measurement against any acoustical modifications that are completed in the future. Follow-up measurements performed can be compared with the baseline data to quantify the changes to the spaces acoustically. The ASHRAE PMP does not provide design criteria for acoustics and instead recommends that subjective evaluations are completed by the occupants of the space. It is the results from these subjective evaluations that may determine if sound isolation, the reverberation time, background noise or any combinations of the three require attention within tested building space.

### Analysis

The PMP states that if between 80% and 90% of the of the room background noise measurements are found to be at or below the noise criteria, then the building can be considered "marginally acceptable." If greater than 90% of the room background noise measurements are at or below the noise criteria, then the building can be considered to be "acceptable." Although not stated, we assume that these same percentages apply to the reverberation time measurements. Unfortunately, this methodology does not address speech privacy.

## SECTION 2: GSA/ASTM MEASUREMENT PROTOCOL

The U.S. General Services Administration employs the speech privacy measurement method outlined in ASTM E1130-02. This standard was written to assess speech privacy in open-plan offices; however, GSA used the same methodology to assess speech privacy in enclosed spaces. Measurements of background noise and sound isolation are conducted per ASTM E1130-02 and ASTM E336-07. This data was then used to calculate speech privacy levels between adjacent spaces and to calculate the predicted percentage of occupants who would be dissatisfied with their level of speech privacy.

The ASTM method requires the following instrumentation:

- A class 1 sound level meter with parallel octave band filters covering 31.5 Hz to 8 kHz
- A type 1 acoustic calibrator
- Annual calibration of sound level meter and calibrator
- Two powered loudspeaker (one for private offices, one for open-plan offices)

### Background Noise Measurements

Background noise measurements shall be conducted in the sample workspaces. The purposes of the background noise measurements are: a) to quantify the noise level of the workspaces and compare the noise levels to the applicable (i.e., ASHRAE, GSA) standards; and, b) use the background noise level (in addition to the sound isolation) to calculate the level of speech privacy between two workspaces. Per ASTM E336 (2007), the background noise measurements should have a minimum duration of 30 seconds. As always, care should be taken to avoid measurement contamination from extraneous noise sources (e.g., people talking, doors closing).

### Sound Isolation

The amount of noise reduction between two spaces is dependent on the type of material between them. Wall partitions, cubicle panels, and acoustically absorptive finish materials all provide a level of noise reduction that is referred to as the 'sound isolation' of a space (ASTM C634, 2010). Sound isolation measurements are conducted between adjacent workspaces, both in open-plan offices and private offices. Increasing levels of sound isolation generally results in higher levels of speech privacy and reduced occupant distraction due to neighbors' activity.

In order to measure the level of sound isolation between open-plan offices, a calibrated, reference loudspeaker plays pink noise (Pink noise – Noise with a continuous frequency spectrum and with equal power per constant percentage bandwidth. For example, equal power in any one-third octave band – from ASTM C634, 2010) in the "source" workstation and one-third octave band sound pressure levels are measured in the "receive" workstation. For private offices and conference rooms, pink noise is generated in the source space and one-third octave band sound pressure levels are measured in both the source and receive space. To calculate the level of sound isolation, the receive sound levels are subtracted from the source sound levels.

### Speech Privacy and Predicted Occupant Dissatisfaction

The background noise level and sound isolation data is then used to calculate the level of speech privacy between two adjacent spaces and the predicted percentage of occupants who would be dissatisfied with their level of speech privacy. These calculations are conducted in accordance with ASTM E1130-08 (2008) as recommended by the ASHRAE PMP (Level 2)(ASHRAE/USGBC/CISBE, 2009) ; this standard is defined for open-plan offices where as the speech privacy and percent dissatisfied calculations for private offices/conference rooms is defined by the Speech Intelligibility Index calculation (ANSI, 1997).

### Speech Intelligibility Index – Privacy Index

The metric for determining Speech Privacy has evolved from the Articulation Index (AI) (ANSI S3.5, 1969) to the more recent Speech Intelligibility Index (SII) (ANSI S3.5-1997). The AI is now superseded by the SII. Both of these speech indices are borne from the same ANSI standard but are calculated in slightly different ways so as to not be considered identical.

The SII is calculated in one-third octave bands and uses the background noise level and predetermined voice levels to provide a percentage of intelligibility, the higher the SII the better the understanding of speech is. A metric of Speech Privacy, or Privacy Index (PI), can be determined by subtracting the SII by 1 (i.e. 1 – SII = PI).

### Reporting

After the measurements have been completed and the data analyzed, a measurement report including the following should be developed:

1. Facility location
2. Measurement locations
3. Description of open-plan office workstations
4. Description of partitions separating private offices, conferences, etc.
5. Description of background noise environment
6. Background noise level at each location
7. Sound isolation between adjacent spaces
8. Predicted speech privacy level between adjacent spaces
9. Average background noise level of open-plan areas and private offices
10. Average sound isolation between adjacent open-plan offices and between adjacent private offices
11. Average speech privacy level in open-plan offices and private offices
12. Predicted occupant dissatisfaction in open-plan offices and private offices

### Analysis

The measurement data and predicted occupant dissatisfaction is compared to the results of the occupant satisfaction surveys. The average background noise level, sound isolation, and speech privacy is compared to other federal office buildings. If a building is found to have acoustical qualities below that of the average federal building or industry standards, recommendations are made to improve the building acoustics.

## SECTION 3: CBE SPEECH PRIVACY PROTOCOL

The CBE measurement protocol is summarized in Salter et al. (2003). This method can be used for both design and for post-construction testing. The measurement protocol is similar to the GSA/ASTM; measurements of background noise level and partition sound isolation are necessary.

After the measurements have been conducted, an analysis is performed to calculate the level of speech privacy and predict the level of occupant dissatisfaction.

For open plan offices, the following analysis is conducted.

1. Predict a speaking voice level. Low voice -- 54 dBA, normal voice -- 60 dBA, raised voice -- 66 dBA, etc.
2. Assume a speech privacy criteria. Normal speech privacy has a factor of 9 and confidential speech privacy has a factor of 16.
3. Measure the noise reduction between work stations.
4. Measure the background noise level.

The level of satisfaction is predicted based on a relationship between speech levels, background noise, noise reduction, need for confidentiality, etc. using information which is similar to Table 2.

For private office acoustical measurements, the following factors are quantified or predicted:

1. Voice level
2. Privacy criterion
3. Effect of source room on speech sound level, this factor adjusts for room size and acoustical quality in source room.
4. The noise reduction between adjoining rooms.
5. Background noise in the receive room.

The level of speech privacy is predicted based on these factors.

## SECTION 4: YOUNG METHOD PROTOCOL FOR SPEECH PRIVACY CALCULATION

Research conducted by Young (1965) simplified the measurement and calculation of speech privacy in private and open offices. The Young Method eliminates the need of octave or one-third octave measurements by only using the single number A-weighted sound level. The procedure thus requires less expensive equipment and simple math.

The Young Method is based on a simple equation. To predict speech privacy,

$$A - C - D = B \qquad \textit{(Young's Method)}$$

Where (A) is Speech Level, (B) is Degree of Speech Privacy, (C) is Sound Isolation and (D) is Background Noise. The Degree of Speech Privacy is a signal-to-noise ratio represented by A-weighted sound levels (dBA). A lower value represents better the speech privacy level (see Table 2).

The Young Method requires the following instrumentation:

- Type I or Type II sound level meter capable of measuring A-weighted sound pressure levels
- Powered loudspeaker
- A CD player or MP3 player for signal playback (i.e. speech-adjusted broadband noise, simulated talking, etc.)

The “speech-adjusted broadband noise” is a steady-state noise with the frequency spectrum that matches a person speaking. This signal provides a source noise for performing measurements of speech privacy (Figure 1).

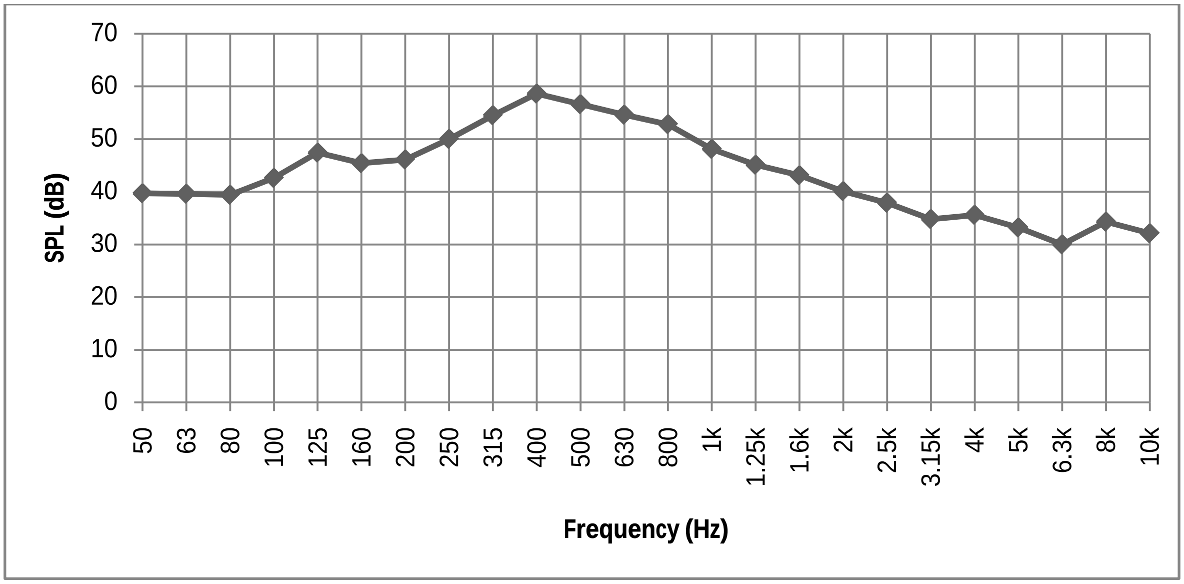



**Figure 1: Speech-Adjusted Broadband Noise**

### Speech Level of Occupant

The speech levels are based on speaking at a distance of three feet. For calculation, a speech level should be chosen from Table 1 to represent the voice level an occupant would use. For example, a typical telephone call would coincide with a low voice level, whereas speaking in a conference room would result in the use of a raised voice.

| Voice Levels (A) | Sound Pressure Level (A-Wtd) |
|---|---|
| Low voice | 54 dB |
| Normal voice | 60 dB |
| Raised voice | 66 dB |
| Loud voice | 72 dB |

**Table 1: Voice Levels for Calculation**

### Speech Privacy Level

During the design of a work environment, the desired speech privacy level can be defined and the remaining variables in the calculation can be estimated. The values to be estimated include: the sound isolation of the intervening partition (Table 3), the background noise in the receive room (Table 4) and the voice level (Table 1). To determine speech privacy via measurements the sound isolation and background noise must be measured, and the voice level is estimated.

| Speech Privacy (B) | Signal to Noise |
|---|---|
| Unacceptable speech privacy | 0 or More |
| Marginal speech privacy | -3 |
| Normal speech privacy | -9 |
| Confidential speech privacy | -15 |

**Table 2: Categories of Speech Privacy**

### Sound Isolation

To measure the level of sound isolation between open-plan offices, a calibrated, reference loudspeaker plays speech-adjusted broadband noise in the "source" workstation and A-weighted sound pressure levels (dBA) are measured in the "receive" workstation. For private offices and conference rooms, loudspeaker noise is generated in the source space and A-weighted sound pressure levels are measured in both the source and receive space. The difference in the measured sound levels between the source and the receive space is the sound isolation of the intervening partition.

| Sound Isolation (C) | Typical Noise Reduction |
|---|---|
| 70" tall office screens | 16 dB |
| Partition built to ceiling grid | 35 dB |
| Partition from slab to slab | 45dB |
| Double stud partition | 63 dB |

**Table 3: Estimated Noise Reduction of Common Office Partitions**

### Background Noise Measurements

Background noise measurements are to be conducted in the workspace per ASTM E336-07 (2007), the background noise measurements should have a minimum duration of 30 seconds. As always, care should be taken to avoid measurement contamination from extraneous noise sources (i.e., people talking, doors closing).

| Background Noise (D) | Sound Level |
|---|---|
| Open Office | 45 dBA |
| Private Office | 38 dBA |
| Executive Conference Room | 30 dBA |

**Table 4: Typical Background Noise**

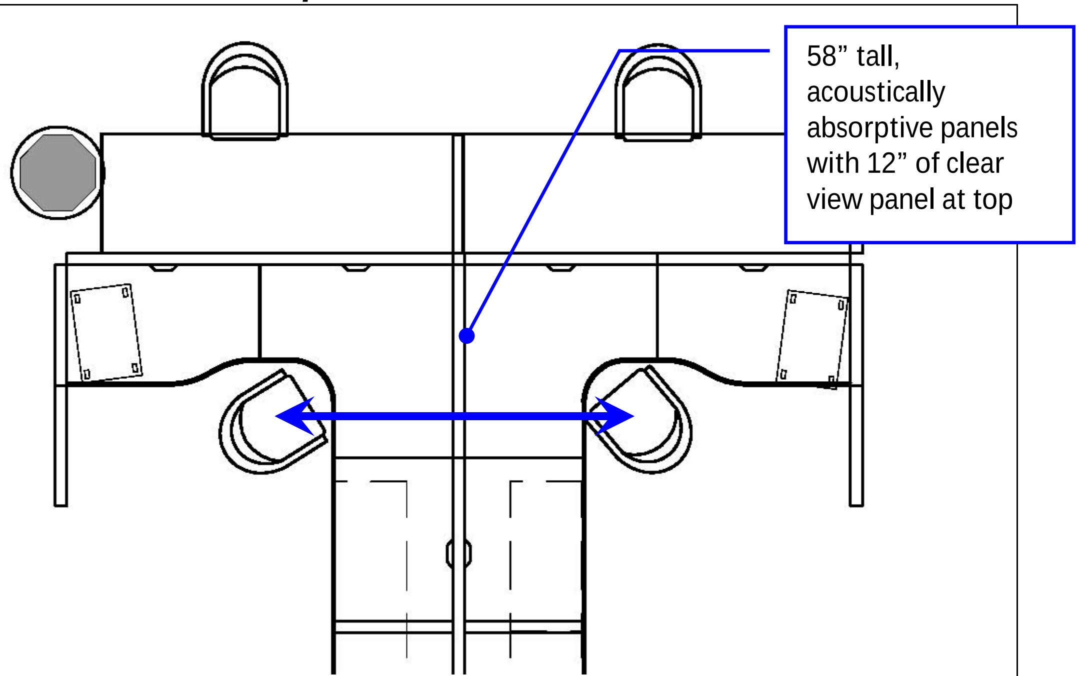
### Analysis

The Young Method can be used to cost-effectively measure whether speech privacy requirements in an office has been achieved. Robert Young's careful comparison to the Cavanaugh et al[1] paper proved that simplifying speech privacy measurements was feasible.

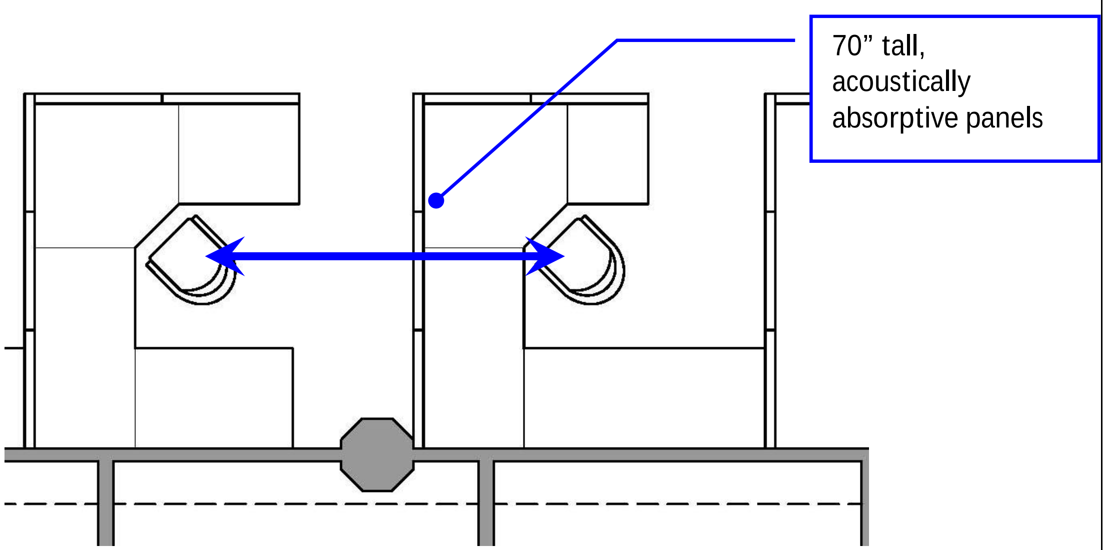
## SECTION 5: MEASUREMENTS

In order to evaluate the accuracy of each measurement protocol, measurements were performed in both open-plan and enclosed (e.g., private office) spaces. Background noise levels, partition sound isolation, and reverberation times were quantified. These measurements were performed in three pairs of open-plan office cubicles and three pairs of private offices. The configuration of each private office pair and each open-plan office pair differed slightly. The following summarizes the tested locations.

## *Open-Plan Offices*

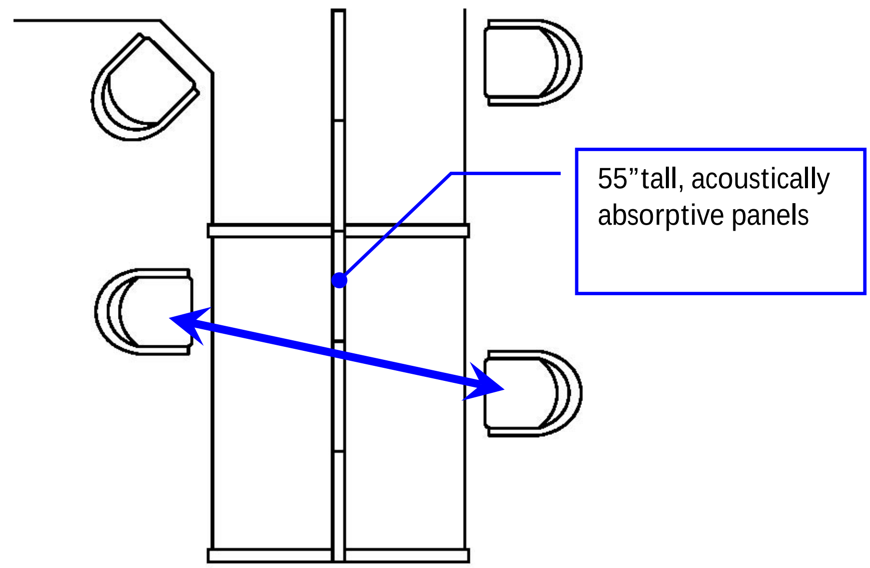



**Open-Plan Office Pair #1**



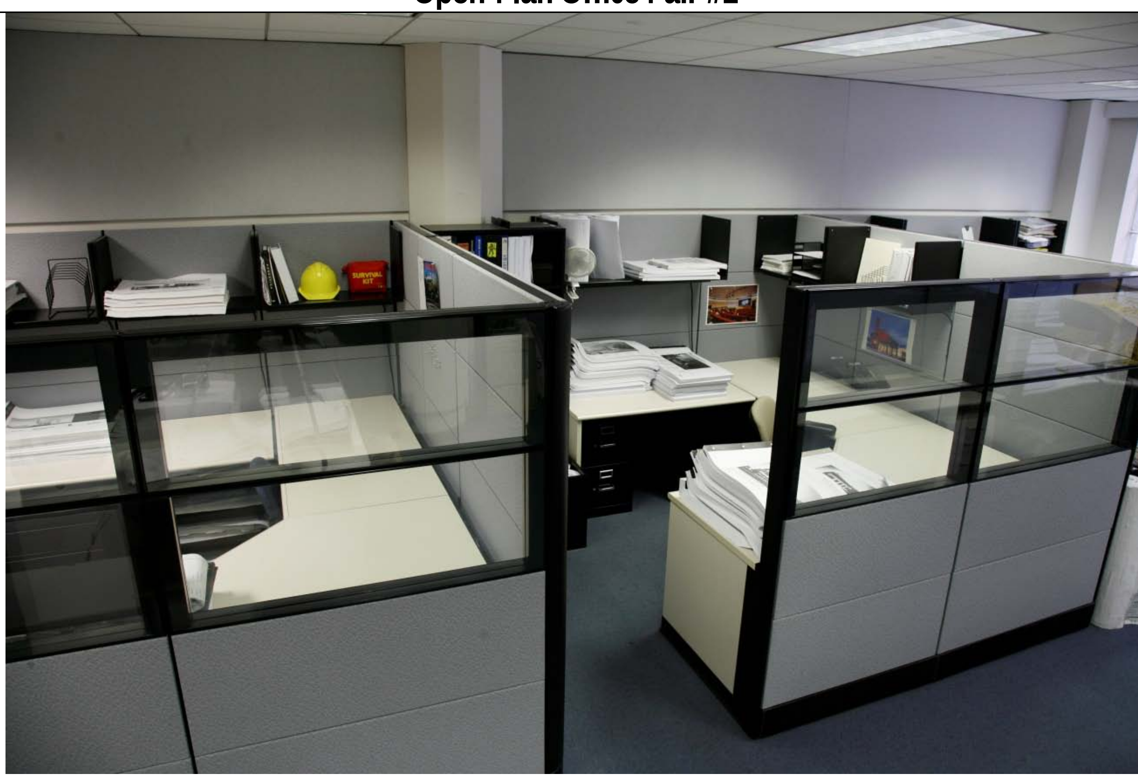

**Open-Plan Office Pair #2**

## *Open-Plan Offices 'cont.*

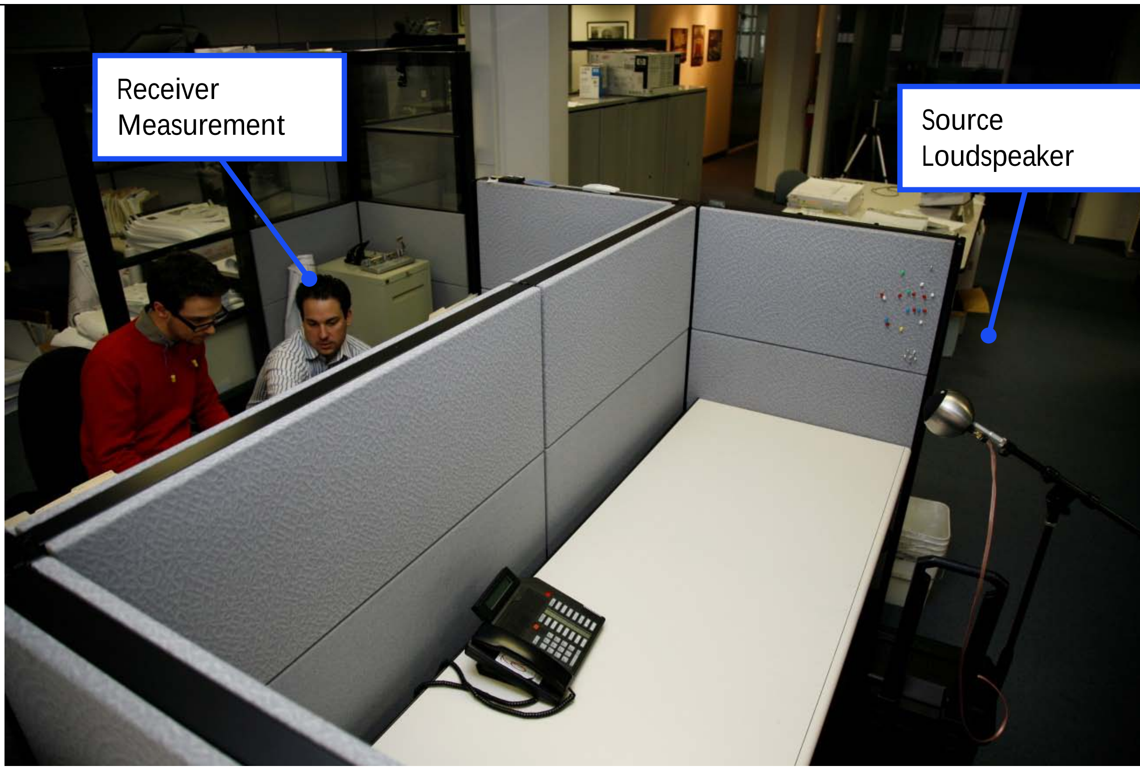



**Open-Plan Office Pair #3**


**Open-Plan Office Pair #1**

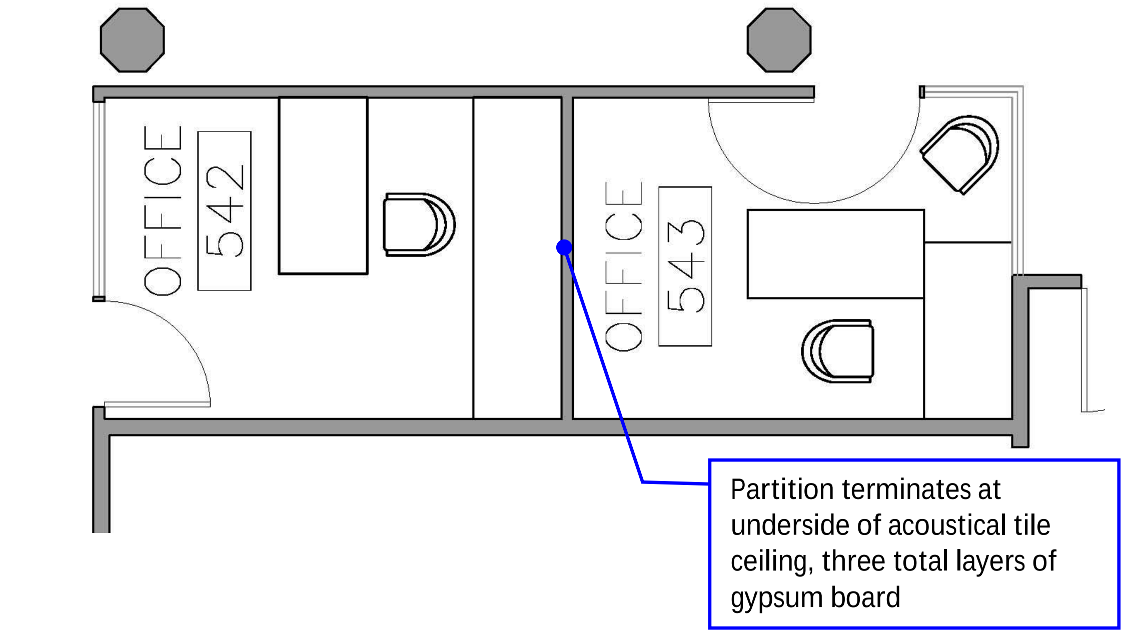


**Open-Plan Office Pair #2**

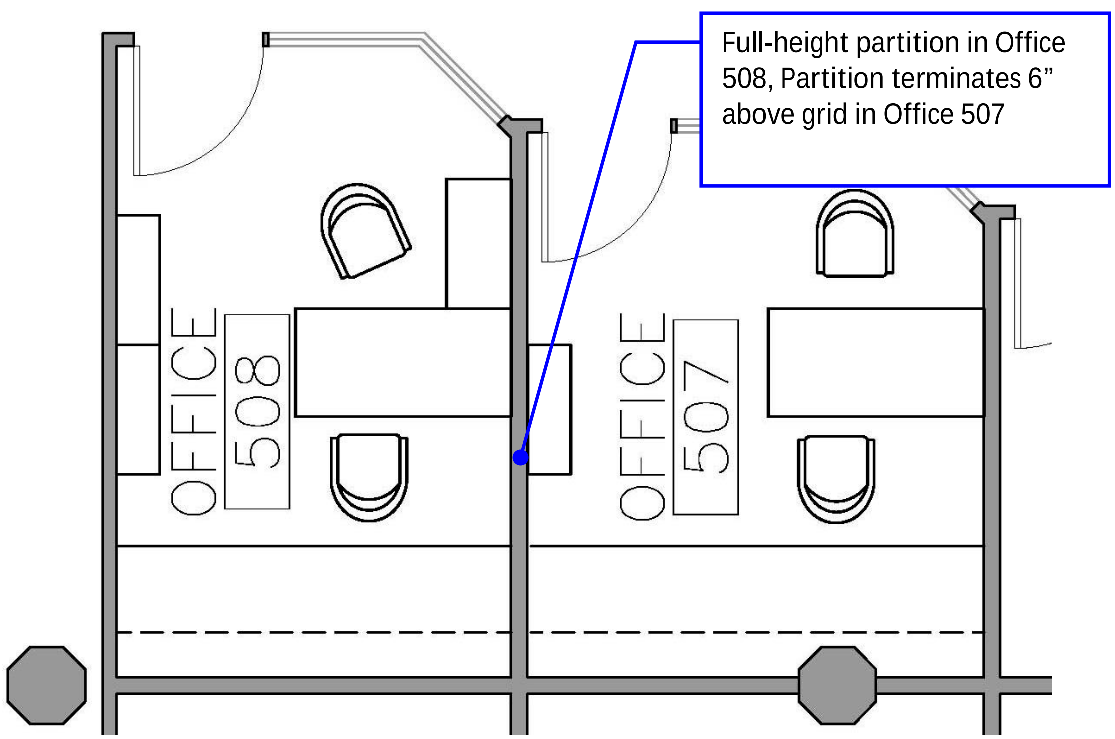



**Open-Plan Office Pair #3**

## *Private Offices*

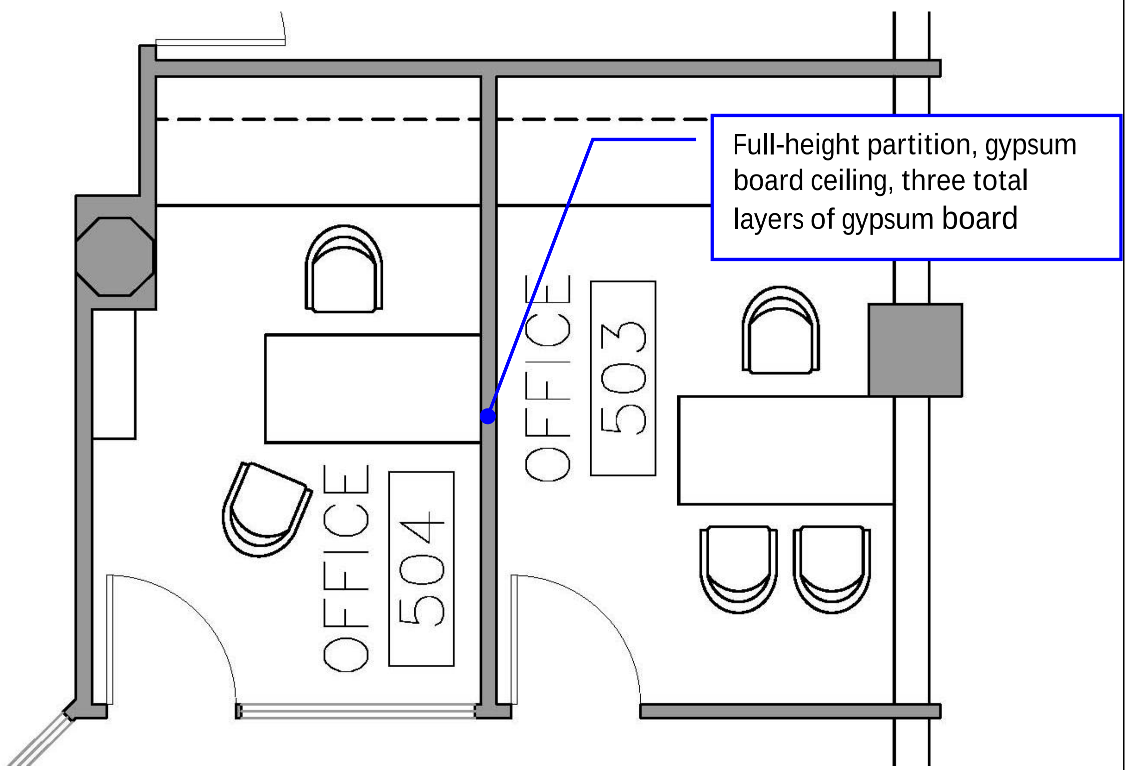



**Private Office Pair #1**




**Private Office Pair #2**

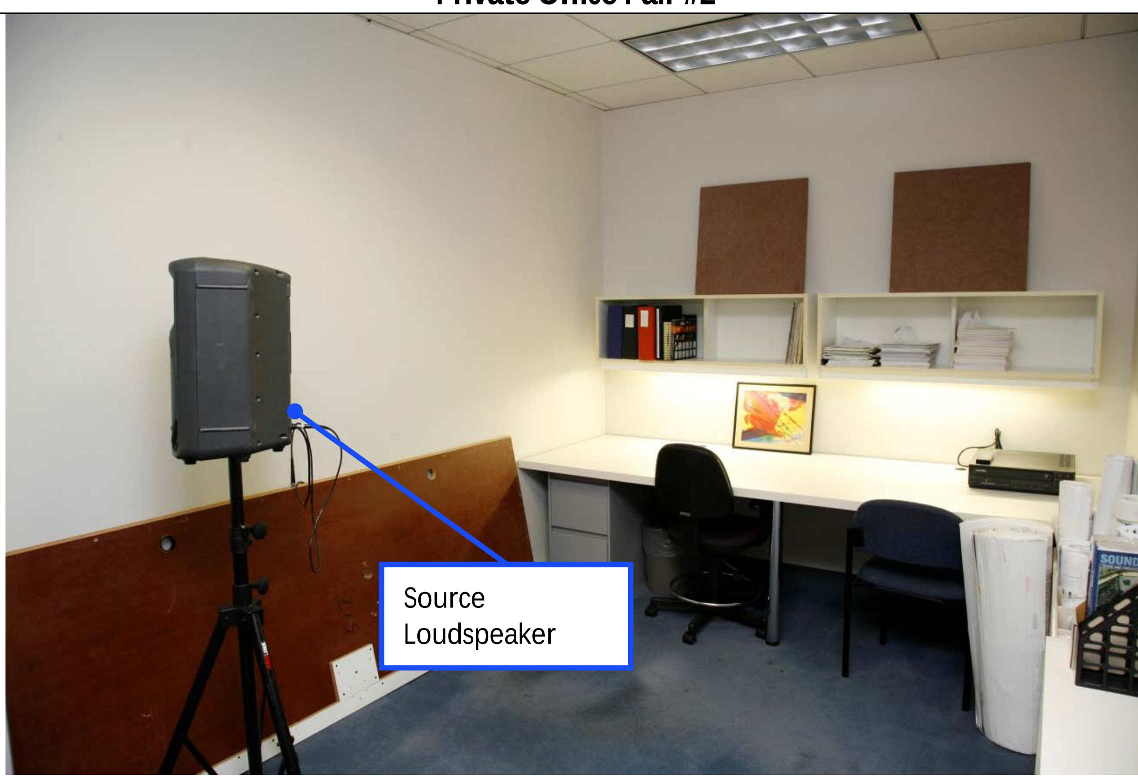
## *Private Offices 'cont.*




**Private Office Pair #3**

**Private Office Pair #1**

**Private Office Pair #2**




**Private Office Pair #3**

## SECTION 6: DATA ANALYSIS AND DISCUSSION

Table 5 shows the relationships among the four speech privacy prediction protocols.

The methods discussed above (ASTM, CBE, Young, ANSI) were used to evaluate each of the office pairs. A normal voice level (60 dBA) was assumed. Table 6 lists the measured data. Speech privacy prediction results are reported in Table 7 and 8.

| Privacy Rank | ASTM E1130 (PI) | | CBE | | Young (dBA) | | ANSI S3.5 (SII) | |
|---|---|---|---|---|---|---|---|---|
| (Best) 1 | > 95 | Confidential | + 3 | Satisfaction | - 15 | Confidential | 0% | Confidential |
| 2 | 70 | Normal | + 7 | Mild dissatisfaction | -9 | Normal | 5% | Acceptable |
| 3 | 50 | Marginal | + 12 | Strong dissatisfaction | -3 | Marginal | 20% | Low |
| (Worst) 4 | < 30 | Unacceptable | > 20 | Extreme dissatisfaction | > 0 | Unacceptable | > 30% | Unacceptable |
| **Est. Cost** | $20,000 | | $20,000 | | $2,500 | | $20,000 | |

**Table 5 Scale of Measurement Methods**

| Open Office | Background (dBA) | NR (dBA) |
|---|---|---|
| **#1** | 40 | 13 |
| **#2** | 35 | 16 |
| **#3** | 35 | 13 |

| Private Office | Background (dBA) | NR (dBA) |
|---|---|---|
| **#1** | 39 | 25 |
| **#2** | 33 | 35 |
| **#3** | 35 | 39 |

**Table 6 Measured Sound Levels**

| ASTM E1130 (PI) | | CBE | | Young (dBA) | | ASHRAE PMP |
|---|---|---|---|---|---|---|
| 89 | Normal | 19 | Extreme | -4 | Marginal | Does not address speech privacy |
| 93 | Normal | 17 | Strong | -8 | Normal | |
| 100 | Confidential | 1 | Mild | -16 | Confidential | |

**Table 7 Private Office Results**

| ASTM E1130 (PI) | | CBE | | Young (dBA) | | ANSI S3.5 (SII) | |
|---|---|---|---|---|---|---|---|
| 34 | Unacceptable | 22 | Extreme | 18 | Unacceptable | 91% | Unacceptable |
| 27 | Unacceptable | 18 | Strong | 18 | Unacceptable | 92% | Unacceptable |
| 11 | Unacceptable | 26 | Extreme | 21 | Unacceptable | 92% | Unacceptable |

**Table 8 Open Office Results**

The definitions of terms in the Tables above are as follows:

**Confidential:**
With people talking in the adjoining room, one would be aware of the conversation, but not understand individual words.

**Normal:**
With people talking in the next room, one would understand an occasional word but not the whole sentence.

**Marginal:**
With people talking in the next room, you would faintly understand every word being said.

**Unacceptable:**
You will clearly hear every word being said in the next cubicle.

**Satisfaction:**
9 out of 10 people will be satisfied with speech privacy.

**Mild Dissatisfaction:**
8 out of 10 people would be satisfied. Sporadic complaints from the remaining 20% will still be expected to occur although corrective action is rarely taken in these cases. Overtime, most people would become accustomed to the noise environment.

**Extreme Dissatisfaction:**
Few people would be satisfied.

**NR:**
Measured noise reduction between source and receiver

## SECTION 7: CONCLUSIONS

The Young Method gives results comparable to the other methods for our small test sample. We recommend that the Young Method be further evaluated and developed because of its cost/effectiveness. It does not require complicated algorithms or reverberation time measurements to acquire accurate enough results. The Young Method is applicable in both private and open-plan offices, is accessible to trained technicians, and does not require an acoustical expert for testing or calculations.

Further evaluations of speech privacy in open and private offices can help refine the Young Method. Because of its simplicity, it can be used to help educate building designers about speech privacy.

### Cost Comparisons

ASHRAE's PMP estimates that the instrumentation including the powered loudspeaker would cost between $9,000 and $12,000. The fees for a third party consultant are estimated to range from $2,000 to $5,000 depending on the number of occupied spaces and measurements required.

The estimated cost for instrumentation necessary to conduct the Young method testing is between $2,000 and $3,000 including the loudspeaker. The cost for services of a third party consultant would be about 1/4 as much as for the other methods. The Young method uses direct dBA measurements and does not require computer analysis to compute 1/3 octave bands for NIC or the speech privacy index. The dBA measurements can be conducted by a trained technician rather than an experienced acoustical engineer.

Based on our experience with acoustical measurements taken by various personnel, we believe that conducting the Young speech privacy measurements will cost 75% less than the other methods. 50% of the savings would be achieved because less data needs to be collected in the field and no laboratory analysis of the data is required afterwards. The other 50% savings occurs because a trained technician would typically be paid about 1/2 as much as an experienced acoustical engineer.

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## ACKNOWLEDGEMENTS

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## Noise Reduction Data

### Private Office #1

| Freq. (Hz) | Source | Receive | Ambient |
|---|---|---|---|
| **50** | 75.3 | 69.3 | 46.1 |
| **63** | 86.2 | 70.2 | 42.8 |
| **80** | 90.6 | 80.6 | 36.3 |
| **100** | 78.8 | 67.7 | 41.4 |
| **125** | 88.4 | 71.5 | 52.6 |
| **160** | 84.9 | 64.6 | 37.2 |
| **200** | 84.2 | 65.9 | 37.6 |
| **250** | 81.8 | 66.3 | 36.1 |
| **315** | 85.0 | 64.1 | 30.1 |
| **400** | 86.2 | 66.3 | 29.3 |
| **500** | 83.4 | 61.6 | 27.4 |
| **630** | 82.3 | 56.8 | 29.1 |
| **800** | 83.6 | 56.4 | 27.9 |
| **1000** | 82.1 | 52.5 | 25.0 |
| **1250** | 80.8 | 47.4 | 23.6 |
| **1600** | 78.1 | 43.0 | 21.7 |
| **2000** | 79.6 | 45.3 | 20.1 |
| **2500** | 82.4 | 43.8 | 16.9 |
| **3150** | 80.6 | 38.3 | 15.1 |
| **4000** | 77.0 | 33.6 | 13.6 |
| **5000** | 75.7 | 33.2 | 13.5 |
| **6300** | 75.4 | 34.1 | 16.7 |
| **8000** | 74.7 | 32.8 | 17.1 |
| **10000** | 75.9 | 33.5 | 11.1 |
| **12500** | 76.4 | 34.0 | 10.8 |
| **16000** | 71.9 | 29.9 | 13.3 |
| **20000** | 61.9 | 19.6 | 15.9 |

**Private Office #2**

| Freq. (Hz) | Source | Receive | Ambient |
|---|---|---|---|
| 50 | 56.6 | 47.4 | 40.2 |
| 63 | 60.3 | 47.4 | 40.7 |
| 80 | 70.2 | 56.1 | 39.3 |
| 100 | 74.9 | 59.8 | 37.2 |
| 125 | 80.9 | 65.0 | 37.8 |
| 160 | 81.5 | 59.5 | 31.1 |
| 200 | 77.5 | 56.5 | 27.7 |
| 250 | 74.2 | 49.3 | 29.6 |
| 315 | 74.0 | 47.0 | 26.9 |
| 400 | 75.7 | 44.2 | 25.5 |
| 500 | 79.1 | 45.6 | 23.2 |
| 630 | 78.1 | 41.4 | 22.0 |
| 800 | 77.3 | 38.6 | 22.9 |
| 1000 | 76.1 | 36.1 | 21.8 |
| 1250 | 73.2 | 31.1 | 20.2 |
| 1600 | 74.5 | 30.0 | 21.4 |
| 2000 | 76.9 | 33.4 | 21.2 |
| 2500 | 77.2 | 33.7 | 19.3 |
| 3150 | 72.7 | 28.5 | 23.0 |
| 4000 | 71.4 | 26.4 | 17.3 |
| 5000 | 62.2 | 19.8 | 15.4 |
| 6300 | 53.2 | 17.4 | 13.8 |
| 8000 | 51.9 | 16.1 | 12.0 |
| 10000 | 45.8 | 15.3 | 11.1 |
| 12500 | 33.0 | 14.6 | 11.8 |
| 16000 | 24.0 | 13.9 | 18.8 |
| 20000 | 20.3 | 14.5 | 17.8 |

**Private Office #3**

| Freq. (Hz) | Source | Receive | Ambient |
|---|---|---|---|
| **50** | 83.5 | 60.8 | 44.3 |
| **63** | 86.8 | 70.4 | 41.6 |
| **80** | 87.7 | 68.4 | 36.1 |
| **100** | 89.1 | 68.9 | 31.2 |
| **125** | 82.9 | 56.8 | 35.8 |
| **160** | 85.3 | 52.3 | 31.6 |
| **200** | 83.4 | 49.1 | 26.1 |
| **250** | 79.1 | 43.8 | 26.2 |
| **315** | 85.2 | 44.8 | 21.6 |
| **400** | 86.5 | 42.4 | 18.9 |
| **500** | 83.9 | 38.8 | 18.0 |
| **630** | 82.6 | 38.8 | 17.5 |
| **800** | 84.6 | 38.5 | 16.8 |
| **1000** | 82.8 | 34.8 | 18.2 |
| **1250** | 81.5 | 33.9 | 21.3 |
| **1600** | 80.0 | 33.3 | 19.4 |
| **2000** | 81.2 | 37.9 | 15.5 |
| **2500** | 82.4 | 40.4 | 12.7 |
| **3150** | 80.8 | 34.2 | 14.6 |
| **4000** | 77.4 | 28.6 | 12.4 |
| **5000** | 76.2 | 26.4 | 12.9 |
| **6300** | 76.0 | 23.6 | 19.6 |
| **8000** | 74.8 | 20.3 | 20.8 |
| **10000** | 76.2 | 18.0 | 10.1 |
| **12500** | 76.5 | 17.9 | 12.1 |
| **16000** | 71.3 | 18.6 | 17.8 |
| **20000** | 61.2 | 22.1 | 19.1 |

**Cubicle Office #1**

| Freq. (Hz) | Source | Receive | Ambient |
|---|---|---|---|
| 50 | 75.3 | 50.5 | 50.3 |
| 63 | 86.2 | 46.7 | 46.7 |
| 80 | 90.6 | 42.3 | 39.2 |
| 100 | 78.8 | 40.2 | 36.6 |
| 125 | 88.4 | 48.4 | 36.8 |
| 160 | 84.9 | 47.3 | 36.0 |
| 200 | 84.2 | 49.3 | 32.8 |
| 250 | 81.8 | 52.9 | 29.1 |
| 315 | 85.0 | 55.8 | 26.6 |
| 400 | 86.2 | 54.1 | 25.8 |
| 500 | 83.4 | 55.7 | 26.5 |
| 630 | 82.3 | 55.3 | 26.6 |
| 800 | 83.6 | 54.2 | 29.2 |
| 1000 | 82.1 | 55.5 | 25.6 |
| 1250 | 80.8 | 54.4 | 23.3 |
| 1600 | 78.1 | 51.6 | 21.5 |
| 2000 | 79.6 | 53.7 | 18.7 |
| 2500 | 82.4 | 54.0 | 16.2 |
| 3150 | 80.6 | 50.9 | 14.7 |
| 4000 | 77.0 | 47.2 | 14.6 |
| 5000 | 75.7 | 43.0 | 12.7 |
| 6300 | 75.4 | 39.8 | 11.3 |
| 8000 | 74.7 | 38.9 | 10.5 |
| 10000 | 75.9 | 33.0 | 9.1 |
| 12500 | 76.4 | 29.9 | 9.4 |
| 16000 | 71.9 | 23.5 | 8.2 |
| 20000 | 61.9 | 15.5 | 8.6 |

**Cubicle Office #2**

| Freq. (Hz) | Source | Receive | Ambient |
|---|---|---|---|
| **50** | 75.3 | 56.8 | 57.6 |
| **63** | 86.2 | 51.7 | 48.0 |
| **80** | 90.6 | 41.8 | 41.5 |
| **100** | 78.8 | 43.0 | 42.3 |
| **125** | 88.4 | 41.1 | 40.0 |
| **160** | 84.9 | 43.8 | 39.5 |
| **200** | 84.2 | 48.2 | 41.5 |
| **250** | 81.8 | 52.3 | 36.3 |
| **315** | 85.0 | 52.0 | 29.0 |
| **400** | 86.2 | 52.4 | 26.5 |
| **500** | 83.4 | 53.7 | 26.0 |
| **630** | 82.3 | 50.5 | 25.8 |
| **800** | 83.6 | 48.7 | 27.8 |
| **1000** | 82.1 | 52.6 | 23.7 |
| **1250** | 80.8 | 54.3 | 22.5 |
| **1600** | 78.1 | 50.2 | 20.3 |
| **2000** | 79.6 | 51.7 | 18.9 |
| **2500** | 82.4 | 50.3 | 16.8 |
| **3150** | 80.6 | 49.8 | 15.3 |
| **4000** | 77.0 | 45.3 | 13.5 |
| **5000** | 75.7 | 42.7 | 12.1 |
| **6300** | 75.4 | 41.2 | 11.1 |
| **8000** | 74.7 | 41.0 | 10.7 |
| **10000** | 75.9 | 35.6 | 10.0 |
| **12500** | 76.4 | 33.4 | 9.1 |
| **16000** | 71.9 | 26.5 | 8.9 |
| **20000** | 61.9 | 17.5 | 9.0 |

**Cubicle Office #3**

| Freq. (Hz) | Source | Receive | Ambient |
|---|---|---|---|
| **50** | 75.3 | 58.5 | 50.3 |
| **63** | 86.2 | 55.0 | 46.7 |
| **80** | 90.6 | 45.3 | 39.2 |
| **100** | 78.8 | 45.6 | 36.6 |
| **125** | 88.4 | 51.1 | 36.8 |
| **160** | 84.9 | 50.2 | 36.0 |
| **200** | 84.2 | 50.7 | 32.8 |
| **250** | 81.8 | 48.3 | 29.1 |
| **315** | 85.0 | 49.1 | 26.6 |
| **400** | 86.2 | 55.7 | 25.8 |
| **500** | 83.4 | 53.3 | 26.5 |
| **630** | 82.3 | 54.1 | 26.6 |
| **800** | 83.6 | 53.2 | 29.2 |
| **1000** | 82.1 | 54.1 | 25.6 |
| **1250** | 80.8 | 55.6 | 23.3 |
| **1600** | 78.1 | 52.6 | 21.5 |
| **2000** | 79.6 | 54.6 | 18.7 |
| **2500** | 82.4 | 53.5 | 16.2 |
| **3150** | 80.6 | 53.1 | 14.7 |
| **4000** | 77.0 | 50.7 | 14.6 |
| **5000** | 75.7 | 48.1 | 12.7 |
| **6300** | 75.4 | 45.1 | 11.3 |
| **8000** | 74.7 | 44.2 | 10.5 |
| **10000** | 75.9 | 38.7 | 9.1 |
| **12500** | 76.4 | 36.4 | 9.4 |
| **16000** | 71.9 | 29.1 | 8.2 |
| **20000** | 61.9 | 19.0 | 8.6 |