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SOUND MASKING SYSTEMS AND THEIR EFFECTIVENESS:
Does Sound Masking Really Work?

Ivan E. Desroches, MRAIC, OAAAS, A.Sc.T., *ivan.desroches@perkinswill.com*

ABSTRACT

As we move toward designing more open offices, clients are faced with having to adapt to unfamiliar types of aural environments. Along with the advantages of open offices also comes the issues of noise disturbance and speech privacy from adjacent workstations, which are often addressed by the introduction of a sound masking system. The question remains, how well do these systems truly work at masking speech? Perkins+Will investigated the effectiveness of the technology by analyzing the user's ability to properly hear spoken conversation after the system vendor validated the system. This unconventional study demanded a different approach than that found in the ASTM E1130 standard method of measuring speech privacy in order to evaluate the subjective nature of the occupants' response to sound.

The method adopted for this study was to conduct a series of Speech Articulation (SA) tests. The results generated a matrix that was used to identify a correct Percentage of Articulation (PA) for each respective environment. The lesser the volunteer's ability to properly discern sounds, the more it can be demonstrated that the system functions as intended.

With the system running, the sound masking consistently lowered the PA values. SA tests also demonstrated that the system had little effect on speech intelligibility in some smaller open areas and had a greater effect in large open office environments. The results also provided a better understanding of the size of the privacy zones and limitations of a sound masking system. Sound masking systems should be selected in conjunction with the layout, scale, materiality and the type of architectural space. Gaining a better understanding of the efficiencies and inefficiencies will help designers yield maximum results.

KEYWORDS: open office, open plan, speech privacy, architectural acoustics, noise disturbance, perceived sound, field test

1.0 INTRODUCTION

The design industry is seeing more initiatives that promote collaboration and engagement between employees. In Canada, an example of this trend is the Federal Government's Workplace 2.0 standards[1]. This results in more open environments with reduced walls and reduced height of workstation screens to maximize natural light. One of the challenges in this transition is to achieve effective speech privacy, which is known to diminish in an open plan. For example, it is not uncommon to have speech understood up to 50 feet away in an open office. Sound masking systems are recognized in the industry as a way to assist in obtaining a higher level of speech privacy in open environments[2]. Organizations such as the USGBC are offering online continuing education courses recognized by architectural associations to raise an awareness of this issue[3]. The sound masking system introduces a specialized ambient sound tuned to interfere with the human voice into the space, as seen in Figure 1. This ambient sound makes it possible for people to converse within a zone, but makes it difficult to understand conversation out-

side of a privacy zone. Although adjacent conversations are still audible, sound masking is meant to diminish the intelligibility of these discussions.

In a temporary relocation space, a confidential client has adopted an office design that predominately uses open workstations. Although the pre-existing office space also included open workstations, the workforce was accustomed to a much larger ratio of enclosed offices to open workstations. The client, who was unfamiliar with sound masking systems, made a strategic decision to procure sound masking and allow the occupant to test the environment before committing to this solution in the final end state project. Throughout the temporary swing space areas, the sound masking system had been installed both in open workstation environments and adjacent to enclosed offices. Perkins+Will was retained to undertake an independent review of the supplier's installation at the temporary swing space to verify the effectiveness of the system.

The onsite investigation took place over two days with the spaces fully occupied. The goal of the testing was to observe the speech hindering effects sound mask-

ing had on the occupants. The data collected was then used to determine to what degree the system actively contributes to hindering the intelligibility of speech. The approach used to test the effectiveness of the system was to perform Speech Articulation tests. This consists of studying the amount of properly understood sounds from volunteers at various distances from source to establish a Percentage Articulation (PA) correctly heard. This unconventional approach uses the sensibility of the human factor of real occupants in the field to establish results. This is quite different than the method used in the ASTM E1130 standard, which uses a noise generator as a sound source and then proceeds to sample large amounts of data of certain frequencies at various locations in order to mathematically formulate a value assigned for Articulation and Privacy[4]. Although the ASTM method is accurate, being able to evaluate the impact actually heard by volunteers brings the advantage of demystifying the realm of acoustics, which is usually associated with complex acoustic measurements and formulas[5,6]. Furthermore, this approach carries a high level of simplicity that helps clients understand the results of the sampled areas and brings with it a sense of individual sincerity.

Figure 1: Conventional sound masking system in suspended acoustical ceiling (Courtesy of Environmental Acoustics Inc. © 2014 K.R. Moeller Associates Ltd).

The perceived speech heard by a receiver is also known to vary depending on user's gender, age, native language as well as his or her position from the speaker (real or artificial)[7]. To attain maximum faithfulness in the accuracy of the data gathered, volunteers from the client's workforce were obtained to fill the position of three males and three females representing various age groups. The volunteers were also screened to exclude acute hearing disorders as to avoid any significant bias in this relatively small sample group.

Volunteers were arranged in a standing position to the right and to the left of the recorded sound source to a maximum of 25 degrees from axis and to three predetermined distances: 15, 25 and 35 feet away (Figure 2).

There were four tests conducted in each area. The first series of word tests was performed with the sound masking off in efforts to collect data that could establish a benchmark comparison with the system functioning. The other three tests were performed with the sound masking on and the volunteers would then rotate their positioning from source for each test. This process would allow the volunteer to be in various distances from source and help determine the extent of the privacy zone. Three series of tests (position B, C and D) with the system on also provided more data to be collected and allow a higher degree of accuracy when averaging the results.

The method was followed with the sound source positioned in an open office area as well as with the sound source positioned in an enclosed office area (with the test subjects outside the office) for each of the three sample floors selected. When the tests were performed from an enclosed space, the sound source was pointed to the door to capture the weakest portion in the sound barrier.
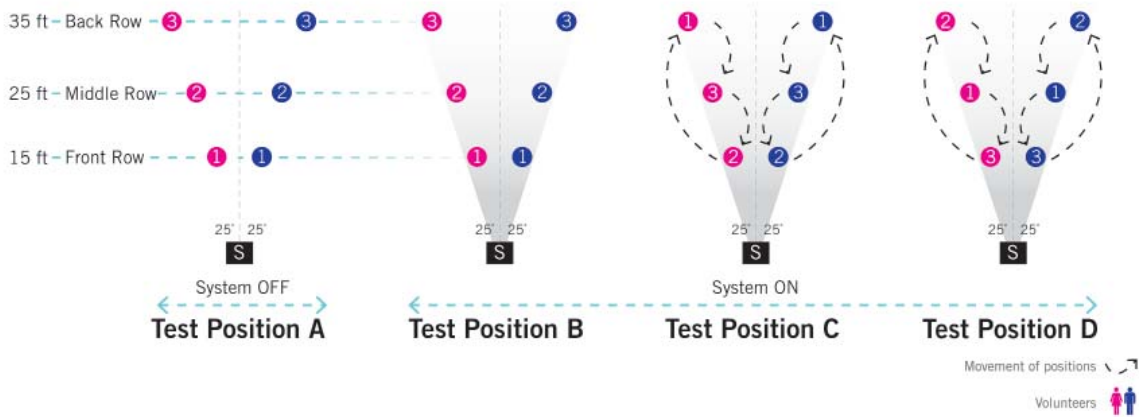

Figure 2: Positioning patterns of volunteers for each test.

The recordings were played back using a male voice to expose the volunteers to a series of 25 simple partial sentences for each test position. The format of the sentences were led with a starting statement, which would help the volunteers follow on their page as well as prepare them for what they needed to attentively listen. The sentence would then end with a nonsensical single syllable word pronounced normally.

Playback Recording

1. The first is BAIT
   [4 second pause]

2. Now try SET
   [4 second pause]

3. Next comes RIB
   [4 second pause]

4. Group 4 is TEN
   [4 second pause]

5. The next is WING
   etc…

Volunteer Listener's Sheets

1. The first is _____

2. Now try _____

3. Next comes _____

4. Group 4 is _____

5. The next is _____

As the recording was being played, a four second pause between each sentence was introduced to allow time for the volunteers to interpret and write down the last word of the sentence they heard. The data was then collected, analyzed with the actual recording and the average of correctly heard words was determined for each row. Given that four positioning pattern (A, B, C and D) were used, this resulted in four series of 25 word tests per area for two areas per floor (open office and closed office), and three sample floors for a total of 600 spoken words used as the basis of collecting data for this analysis.

The original recording of the word tests was done using a microphone, an external USB soundcard by M-Audio for analog to digital conversion, computer and Audacity software to produce an accurate 96/24 high resolution audio recording (Figure 3). At the time of testing, the sound masking system had been installed and calibrated by the vendor and the spaces were fully occupied by the tenant. Before performing any on-site SA testing, some basic training was given to the volunteers to brief them on the objective of the tests and to their responsibilities of recording what they hear. The digital playback system consisted of the same computer with an external USB soundcard by M-Audio to conduct

the digital to analog conversion. This sound card was connected directly into an amplifier, which acted as the speaker by use of patch cord to maintain high resolution reproduction of the recording. Given that the degree of absorption varies in each sampling area, which would affect the playback amplitude, it was preferred to calibrate on site at each test area. Prior to starting each series of 25 word test, the source sound coming from the recording was individually calibrated on site (with the sound masking system turned off) by using the sound pressure level meter measured at three feet from source. Because of the normal variance in the human voice when pronouncing spoken words and to take into account the possibility of impulsive raised voice efforts, the recording play back could not be an exact consistent amplitude. Therefore, the sound source playback produced an A-weighted sound level that fell within the following parameters measured with the sound masking system turned off:

- 60dB (brief peaks up to 70dB) amplitude at 3 ft used for SA testing in open area
- 65dB (brief peaks up to 75dB) amplitude at 3 ft used for SA testing from small enclosed offices
- 70dB (brief peaks up to 80dB) amplitude at 3 ft used for SA testing from large enclosed room

Figure 3: Playback equipment used during the onsite Speech Articulation testing.

The amplifier acting as the speaker used to reproduce the recording was carefully positioned on top of pre-existing desks and tables is the sample areas. The position of the speaker located the sound source approximately 36 inches above finish floor and to a maximum of nine degrees off of vertical axis with the volunteer's first row and to a maximum of 25 degrees on each side of the horizontal axis.

According to the Noise Criteria Curve, office environments should be designed to NC-45, but it is not unusual that these types of occupied spaces reach up to an amplitude of 50dB depending on the circumstances of the building systems. The sound masking system's uniformity phasing, zoning, sound spectrum and sound levels of these sample areas were fully commissioned by the manufacturer. The actual ambient sound measured in the six spaces of levels 14, 16 and 18 averaged at 47dB with the sound masking system functioning as validated by system installer. Given that the volume of the tested spaces was smaller than 10,000 cubic feet, the level of reverberation was presumed negligible and therefore not considered as a factor in formulating the PA.

To help evaluate the relationships of the results gathered from the volunteers, a general guideline needed to be developed. The ASTM 1130 standard for speech privacy uses pink or white noise and then the results of the sound level measurements are used to calculate a value assigned in an Articulation Index (AI)[4]. Theoretically, the lower the AI, the less words can be properly articulated in that given environment and the higher values would be indicative of better articulation of spoken words. Therefore, an AI lower than 0.20 would require concentrated effort to follow a conversation and yield a quasi-private area whereas an AI above 0.30, speech would be well understood and provide an unacceptable privacy. This standard also identifies how these values can be directly translated into speech Privacy Index (PI) values as the inverse of AI. PI values range from 0 to 100, in which a PI of 80 and higher would generally achieve speech privacy. The standard also acknowledges the need for further research to establish the relationship of articulation index to speech privacy. In contrast to the ASTM E1130 standard test method, this case study records the subjective response of the human condition and their actual ability to properly hear spoken words from a recording in a field environment. This fundamental difference in the testing necessitated the need to develop a unique classification that could be used as a guideline for the percentage of correctly heard sounds. This newly developed approach yields speed and simplicity with tangible real life results. With the standards presented used as reference and with the help of the theories obtained from the book Acoustical Designing in Architecture[8], we developed a simple classification chart that was used to evaluate the data gathered from volunteers (Table 1).

Table 1: Syllable articulation classification chart.

SYLLABLE ARTICULATION CLASSIFICATION	
PA Correctly Heard	**Likelihood of intelligibility**
95 to 100	Extremely easily understood
85 to 94	Very good
75 to 84	Satisfactory but attentive listening is required
65 to 74	Barely discernable and fatiguing to the listener
0 to 64	Speech not heard suitably

The ASTM E1130 defines confidential speech when speech cannot be understood[4]. Therefore, the worse the speech intelligibility PA observed, the more it will demonstrate that the sound masking system is working effectively. Considering that most spoken words have multiple syllables and that if 25 percent of those sounds are not recognized correctly, full words not correctly understood would be in excess of 25 percent. The missing elements of a sentence would make it difficult to understand and follow in an ongoing conversation. For the purpose of this case study, a PA 74 and lower was considered as the threshold where an environment hinders speech intelligibility.

2.0 FINDINGS

Many factors may contribute in the variation of the final results, such as the limitation of participants' normal hearing range, the level of focus volunteers are able to devote, possible momentary distraction during tests conducted, the participants' native language, the clarity of the recording, articulation of the word test and the location of obstructions that would block or diffract sound.

Results were all scored by one individual to ensure consistency. Judgment made on the observations sheet would allocate a correct score for pronunciation of the sounded word and not on spelling. The data collected

was then used to populate a matrix of values for each type of the tested area. This matrix identified the participants' responses for three open offices and the adjacencies to three enclosed offices. The results of a 25 word test from each row were averaged out between the six volunteers to generate PA value to an accuracy of two decimal places for the respective sample area.

2.1 Review of Open Office Areas

On the 14th floor, we tested an open office area occupied by two executive assistants, as seen in Figure 4. The area is designed as a formal reception point and is finished with hard walls and ceiling surfaces, along with a commercial carpet. The results of the 14th floor, with the system off, averaged PA 90 for the front row, 85 for middle row and 92.50 for the back row resulting in speech being very well understood in this space. With the sound masking system on, the average PA was recorded as 87.50 for the front row, 75.83 for the middle row and 84.17 for the back row. This results in speech intelligibility being very good along the front row, satisfactory along the middle and very good again along the back row. Given the size and layout of this space and the hard surfaces, it is understood that the sound was reflecting off of the wall and ceiling hard surfaces to the back row of this space. It was concluded that sound masking has a marginal effect and hinders very little of the speech intelligibility within this space.
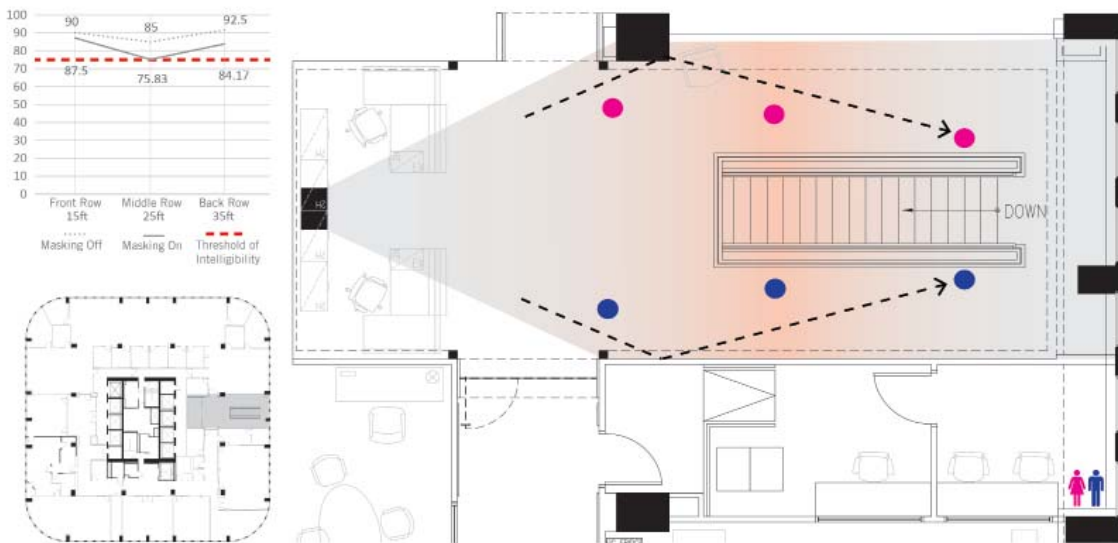

Figure 4: 14th floor plan of SA tests with PA results for the sample open plan environment.

Perkins+Will then sampled an area of the 16th floor, which is characterized by open, fabric-clad workstations, gypsum board walls, and mineral fiber lay-in ceiling tiles (Figure 5). The workstation panel height was set at 54 inches. The results of the 16th floor with the system off averaged PA 97.5 for the front row, 92.5 for middle row and 85 for the back row, resulting in speech being extremely easily understood to very good. With the sound masking system on, the average PA was re-corded as 87.94 for the front row, 71.27 for the middle row and 53.25 for the back row. This results in speech intelligibility being very good along the front row, barely discernable along the middle row and not heard suitably along the back row. It is understood that the sound masking is helping in this environment and has contributed to further hindering speech intelligibility within the range of 24 feet away from source.
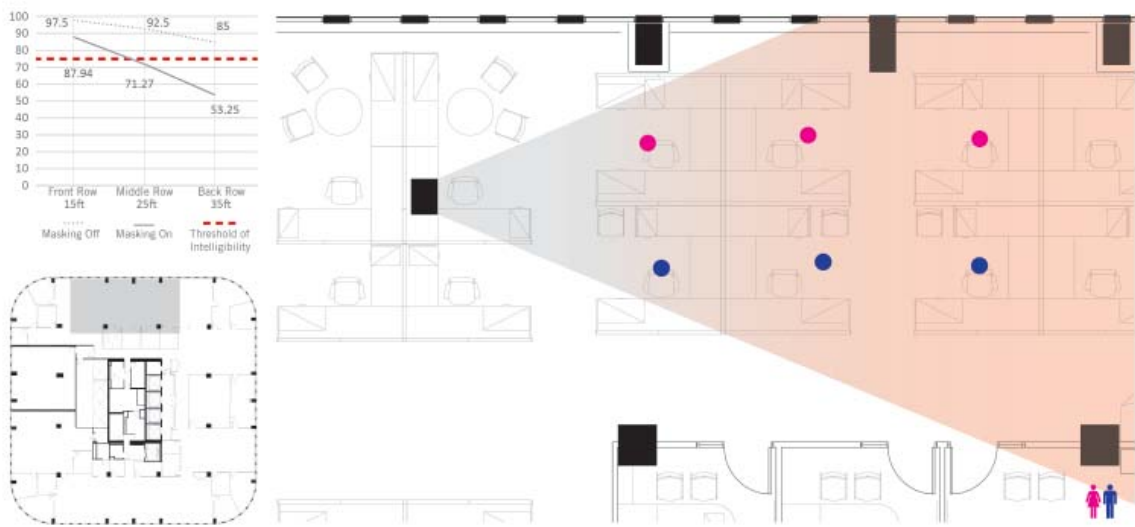
Figure 5: 16th floor plan of SA tests with PA results for the sample open plan environment.
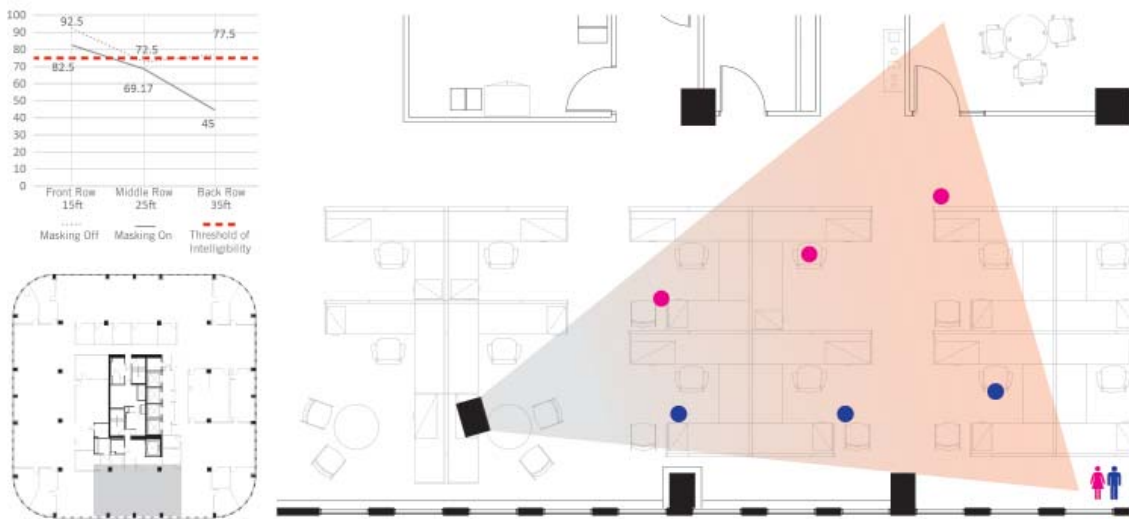

Figure 6: 18th floor plan of SA tests with PA results for the sample open plan environment.

Perkins+Will sampled an area of the 18th floor (Figure 6). The material and spatial characteristics of this floor were similar to the 16th floor. The results of the 18th floor with the system off averaged PA 92.5 for the front row, 72.5 for middle row and 77.5 for the back row resulting in speech being very good to satisfactorily heard. With the sound masking system on, the average PA was recorded as 82.50 for the front row, 69.17 for the middle row and 45 for the back row. This results in speech intelligibility being satisfactory along the front row, barely discernable along the middle and back row. It can be concluded that the sound masking is helping in this environment and has contributed to further hindering speech intelligibility within the range of 22 feet away from the source.

2.2 Review of Enclosed Office Areas

The 14th floor sample area was finished with commercial carpeted floor, hard wood panel walls and gypsum ceiling, as seen in Figure 7. The partition between the office and the adjacent corridor extended up to structure above. The results with the system off averaged PA 35.00 for the front row, 37.50 for middle row and 0 for the back row resulting in speech that is not heard suitably. With the sound masking system on, the average

PA lowered even further to 30 for the front row, 23.33 for the middle row and 0 for the back row. The additional lowering of PA results in diminished speech intelligibility. However, the wall assembly alone is observed to adequately reduce PA below the threshold of intelligibility.

The 16th floor finishes included commercial carpeted floor, gypsum wall assemblies in the office and suspended acoustical tiles in the office (Figure 8). The adjacent open office area was finished with commercial carpet, acoustical tile ceiling and with system furniture of 54 inches high. The partition between the office and the adjacent corridor stop short of the structural slab and only extend up to the underside of the suspended ceiling system. Samples taken in this area, with the sound masking system functioning, showed a substantial drop in PA levels when compared with the sound masking system off. A drop of 54.17 in PA levels for the front row, a drop of 30 for second row and a drop of 5 in PA levels for the back row. The additional lowering of PA results in diminished speech intelligibility. However, the wall assembly alone seems adequate to reduce PA below the threshold of intelligibility.
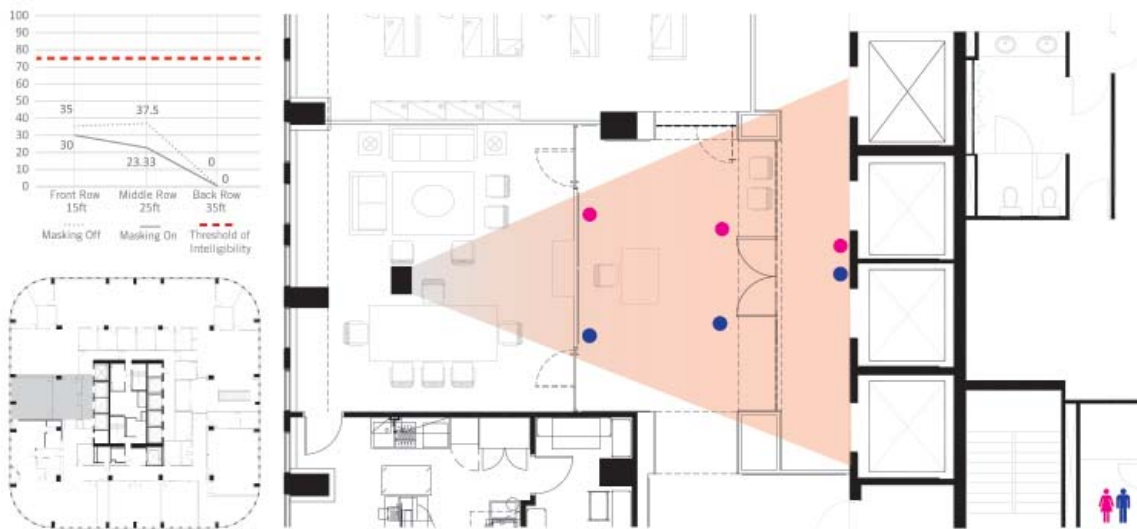

Figure 7: 14th floor plan of SA tests with PA results from the sample enclosed office environment.

The 18th floor was similar in finishes with partitions extending up to underside of ceiling system, as seen in Figure 9. Results were generally similar to that of the 16th floor, since it showed a consistent lowering of the PA level with the system running. In this sample we noticed that people within 20 feet of the source sound will properly hear conversations even with the presence of a wall. Although additional diminished speech intelligibility was observed, the wall assembly alone seemed adequate to reduce PA below the threshold of intelligibility when further than 20 feet away from source. Volunteers positioned within 20 feet from source would have intelligibility affected only when the sound masking system is on.

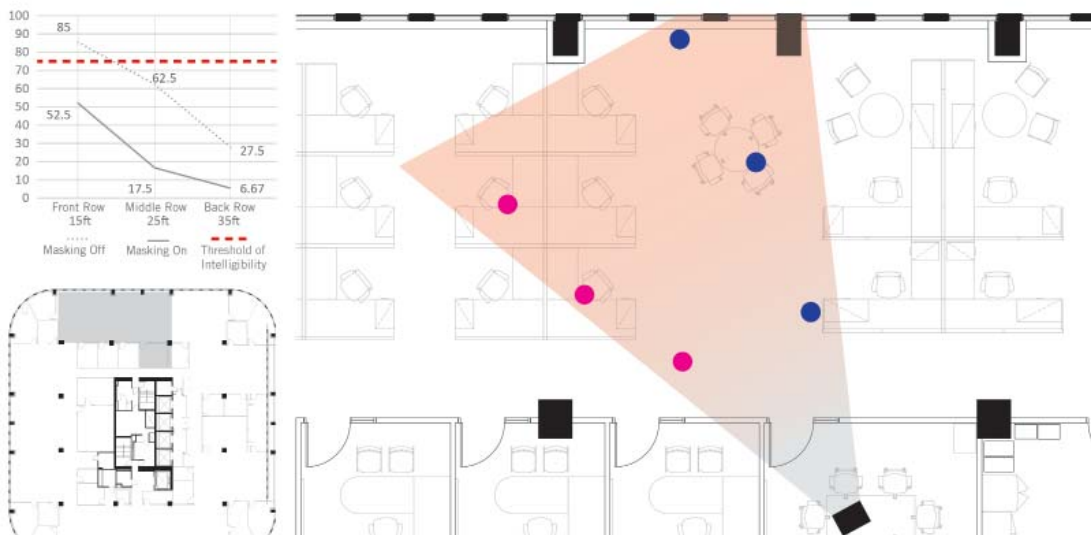Figure 8: 16th floor plan of SA tests with PA results from the sample enclosed office environment.

Figure 9: 18th floor plan of SA tests with PA results from the sample enclosed office environment.

3.0 GENERAL SUMMARY OF FINDINGS

3.1 Average Performance Results When Used in Open Office Environments

Figure 10 shows the arrangement of volunteers and distances from sound source that was used in an open office. Figure 11 shows the average PA results for the sample areas of open office enviroments. When we review the results of the three floors, with system off along the front row, the average PA is 93.33 percent, which yields that speech is very well understood. When we compare these results with the same front row position with the sound masking system running, the average PA is reduced to 85.98 percent, though lower, is still within the very good intelligibility range. Although the sound masking system has resulted in diminished intelligibility, speech privacy has not been achieved at a distance of 15 feet away from source.

Reviewing the results of the three floors, with system off along the middle row, the PA average is 83.33 percent, which yields that speech intelligibility is satisfactory, but attentive listening is required. When we compare these results with the same middle row position with the sound masking system running, the PA average is reduced to 72.09 percent, which is barely discernable to the listener. It is understood that sound masking is contributing to reducing speech intelligibility when standing 25 feet away from source.

Studying the results of the three floors, with system off along the back row, the PA average is 85 percent, which yields that speech intelligibility is very good. When we compare these results with the same back row position with the sound masking system running, the PA average is reduced to 60.80 percent to speech not heard suitably. It is understood that sound masking makes speech incomprehensible standing 35 feet away from source.
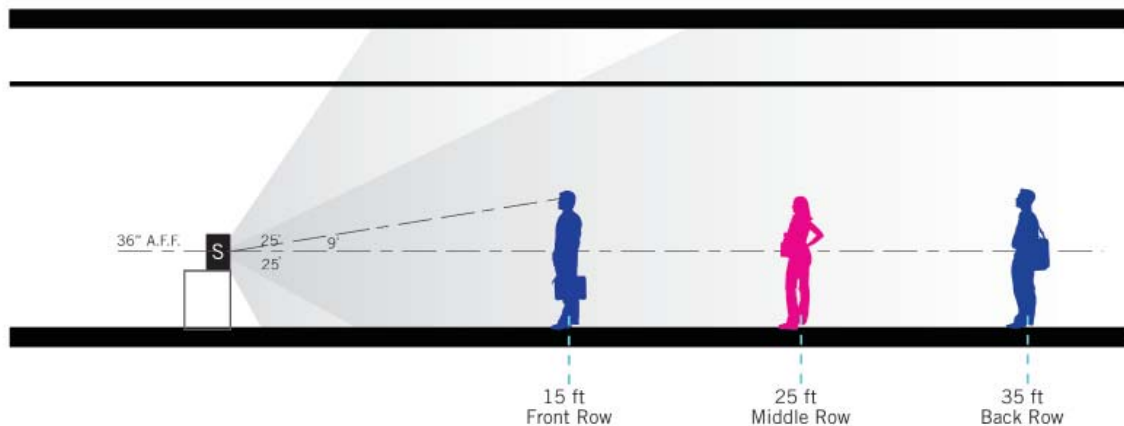

Figure 10: Arrangement of volunteers from sound source in typical open office environments.
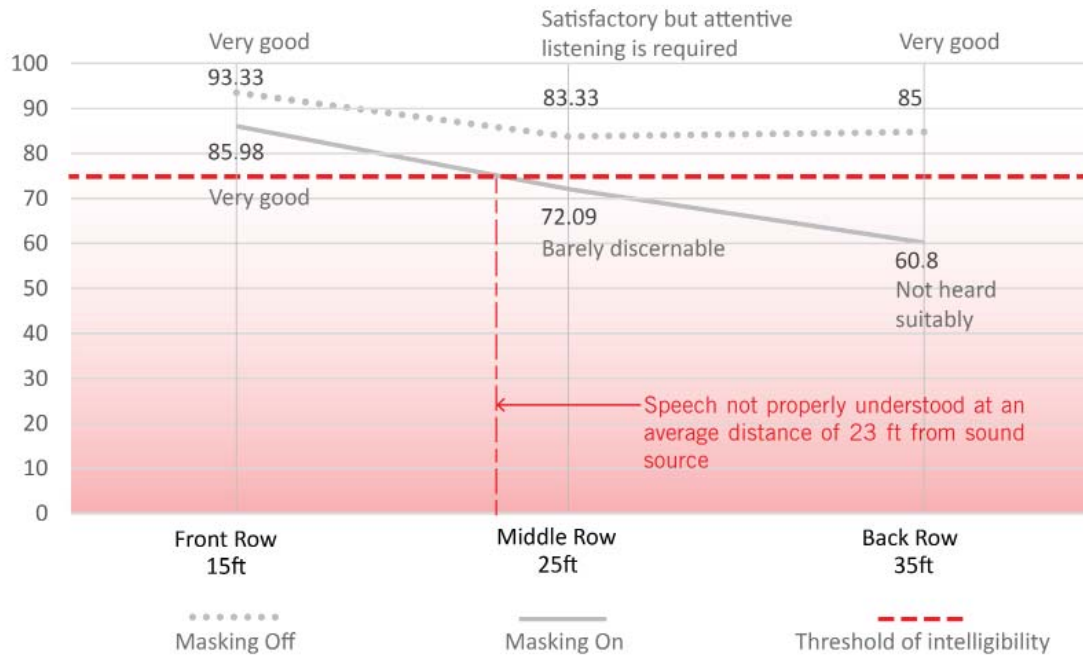
Figure 11: Average PA results from open office environments.

3.2 Average Performance Results When Used Adjacent to Enclosed Office Environments

Figure 12 shows the arrangement of volunteers in relation to sound source adjacent to enclosed office environments, and Figure 13 summarizes average PA results for the sample areas adjacent to enclosed office enviroments. When we review the results of the three floors, with system off along the front row, the PA average is 63.33 percent, which yields that speech is not heard suitably. When we compare these results with the same front row position with the sound masking system running, the PA average is reduced to 31.77 percent and speech is still not heard satisfactorily. It is understood that the average partition alone seems able to reduce speech articulation below the threshold of intelligibility. However, the sound masking system further diminishes the PA. A higher PA was observed at floor 16 and 18, where the partition did not extend up to structure above. It is understood that when devising corridor walls stop at the ceiling system, the average PA was 77.5. People standing at 15 feet from source would be able to hear satisfactorily.

Reviewing the results of the three floors, with system off along the middle row, the PA average is 43.33 percent, which yields that speech is not heard suitably. When we compare these results with the same middle row position with the sound masking system running, the PA average is reduced to 13.61 percent and speech is still not heard satisfactorily. It is understood that the partition alone seems able to reduce speech articulation below the threshold of intelligibility. However, the sound masking system further diminishes the PA.

Studying the results of the three floors, with system off along the back row, the PA average is 10.83 percent yielding that speech is not heard suitably. When we compare these results with the same back row position with the sound masking system running, the PA average is reduced to 2.22 percent and speech is still not heard satisfactorily. It is understood that the partition alone seems able to reduce speech articulation below the threshold of intelligibility. However, the sound masking system further diminishes the PA.
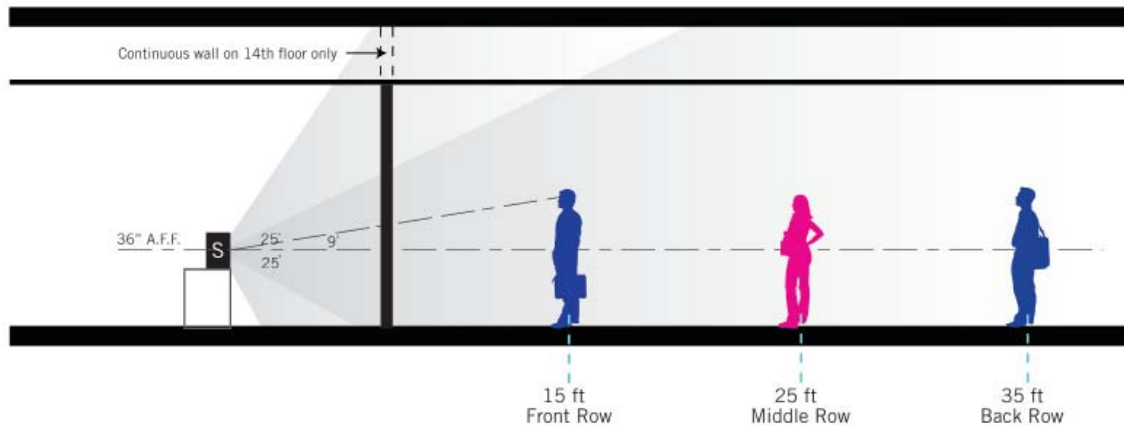
Figure 12: Arrangement of volunteers from sound source adjacent to enclosed office environments.
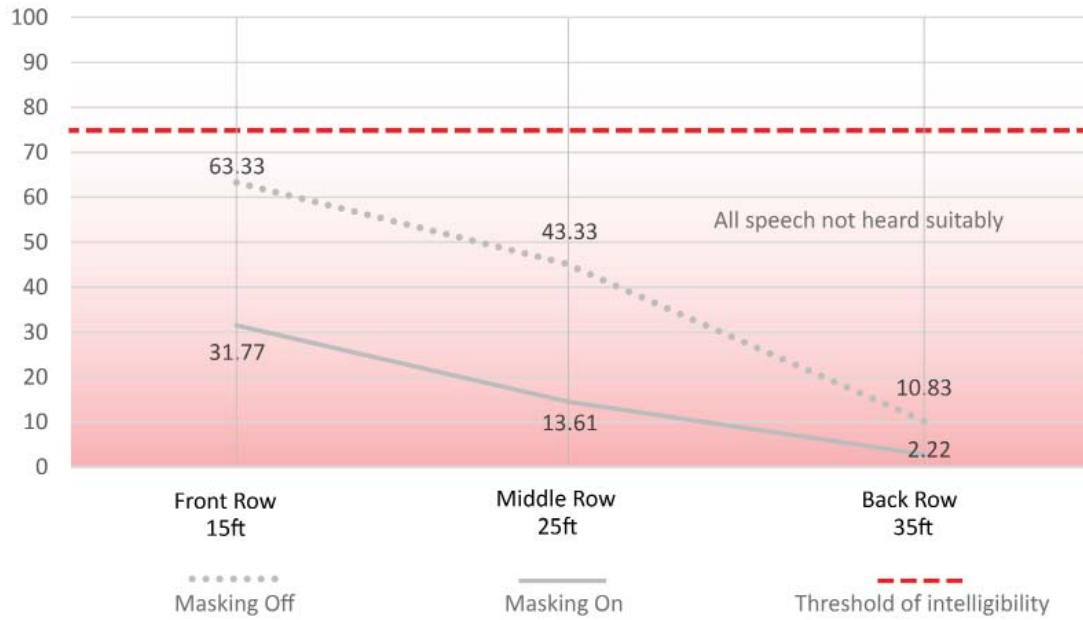
Figure 13: Average PA results for enclosed office environment.

3.3 Privacy Zone

The inherent characteristics of a sound masking system will also impact the size of speech privacy zones. A speech privacy zone is defined as the aural arena in which people can clearly converse and understand conversational speech. Given that the findings endorse that enclosed offices are generally private, a closer look at the impact sound masking has on open areas is warranted.

In an open office environment with the sound masking system off, the volunteers' position in the back row achieved an average PA of 85, which is classified as very good intelligibility. No tests were performed with volunteers beyond 35 feet from sound source and it is presumed that adequate speech intelligibility heard in this environment would exceed this distance. When the same open environment is compared with the system functioning, we observe that the threshold of intelligibility at a PA of 74 reduces the privacy zone. This identifies that on average, in an open office environment, speech can be properly heard within a 23 feet radius of the speaker and that people positioned outside of this zone would not properly understand or be able to suitably follow ongoing conversations, as seen in Figure 14. This finding suggests that in the presence of an active sound masking system, there is a tangible improvement in the size of the privacy zone that should also contribute to reducing adjacent disturbances.

4.0 CONCLUSION

The recorded and calculated PA given in this report are a function of the specific environment and may not directly apply to other project environments. Although this data raises an awareness on how the sound masking system behaves in difference spaces, the following conclusions are offered.

The Speech Articulation testing conducted along with the results gathered from the volunteers demonstrate that in the presence of an active sound masking system, speech recognition is consistently lowered, which provides an elevated level of speech privacy. It is generally understood that the further away the listeners are positioned from a sound source, the PA is also reduced due to the reduced level of sound energy. When comparing the results from the sound masking system turned off and with the system turned on, similar effects in the reduction of PA have been observed. This would indicate that having a sound masking system in place would have similar effects on the occupants as distancing the listener from source, which in turn helps to hinder intelligibility of speech.

The sound masking system does not considerably affect speech privacy when conversational speech is broadcast from enclosed offices. This is attributed to the physical partition, which generally acts as a sufficient sound barrier. There were variances noticed
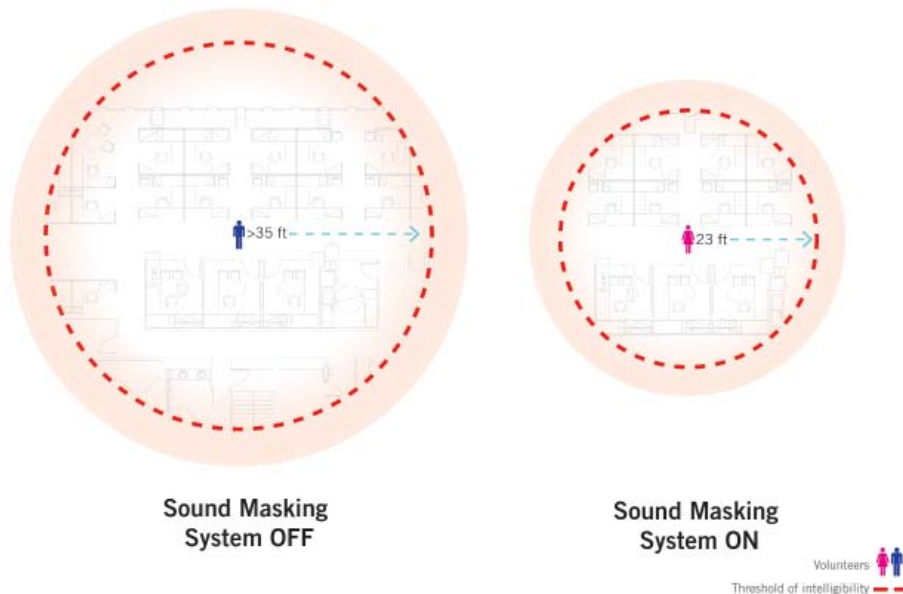

Figure 14: Extent of Privacy Zone diagram.

on the impact to occupants in the near vicinity to an enclosed office. These PA values varied from speech not heard suitably when adjacent partition extend to structure above to speech heard very well when adjacent partitions stop at the suspended ceiling system. Where the speech was being heard very well along the front row, the sound masking did hinder speech intelligibility in the range of 20 feet from sound source of the enclosed room. From a practical sense, this means that in the absence of a sound masking system, people walking through the nearby corridor would hear confidential discussions that would occur from the office. This stresses the importance of proper construction of partitions and their respective doors to act as virtuous sound barriers. Given that site workmanship of said barriers may vary depending on contractors or trades, there is an inherent benefit to have sound masking systems in order to ensure speech privacy is maintained immediately adjacent to enclosed offices, especially when partitions do not extend to structure above.

The sound masking system hinders speech intelligibility, enhancing speech privacy in a privacy zone in the range of 23 feet away from source when used in open office environments. The efficiency of the sound masking system seems to be reduced when used in smaller open office environments where nearby walls and ceilings are made of elevated amounts of hard surfaces. This implies that first order reflections would reinforce the sound energy further in the back row. This stresses the importance of designing spaces with materials that have a good absorption to reduce intelligibility to speech and to help reduce the size of the privacy zone.

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