Title

Designing acoustically successful work places: a case study assessment of the speech privacy and sound isolation of space having underfloor air distribution systems

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DESIGNING ACOUSTICALLY SUCCESSFUL WORK PLACES: A CASE STUDY ASSESSMENT OF THE SPEECH PRIVACY AND SOUND ISOLATION OF SPACES HAVING UNDERFLOOR AIR DISTRIBUTION SYSTEMS

Charles M. Salter, P.E.; Randy D. Waldeck

ABSTRACT

The use and interest in underfloor ventilation systems has been growing due to the systems' energy savings and inherent flexibility. Because the air distribution openings are in the floor, there has been concern over excessive sound transfer between adjacent spaces through the floor plenum, which could lead to unacceptable levels of speech privacy and other acoustical problems.

Charles M. Salter Associates was hired to provide acoustical input for room acoustics and sound isolation between spaces in an office building incorporating an underfloor air distribution system. The office spaces had differing acoustical requirements, for which five wall types were specified based on the levels of noise reduction and speech privacy required between spaces. Standard offices had walls that terminated at the top of the raised floor and the floor plenum was left open, while executive offices and conference rooms had an acoustical septum added in the floor plenum at the location of the common wall. This septum was installed to reduce the transfer of noise in the floor plenum between adjacent spaces. Finally, full-height walls were specified for adjacent spaces requiring the highest level of noise reduction. All partitions were extended to the slab above, with offset return air transfer grilles installed on the corridor or open plan side of the offices, to minimize the potential flanking sound path. After construction was completed, acoustical measurements were conducted to quantify the level of noise reduction and speech privacy between adjacent spaces.

The overall level of speech privacy between all the various tested spaces met normal privacy standards. The noise reduction performance of the walls without acoustical septums was generally a few points lower than the noise reduction of the same wall as tested in a laboratory without a raised floor. The noise reduction performance of the walls with the acoustical septum was generally the same as the same wall's performance in the laboratory. This data seems to indicate that the acoustical septum was effective in reducing noise transfer through the floor plenum, and an acoustical septum may be warranted for spaces requiring high levels of speech privacy.

CONTENTS

1.0 PROJECT BACKGROUND AND INTRODUCTION

Architects, mechanical engineers, and facility planners are interested in utilizing underfloor ventilation systems because of energy conservation, flexibility and other potential benefits. Since the air distribution openings are in the floor, concern has been expressed about excessive sound transfer between adjacent spaces, leading to unacceptable speech privacy and other acoustical problems. The purpose of this case study is to quantify the sound transfer in an under-floor office environment where acoustical design is an important consideration.

Acoustical measurements were taken in a client's completed building with an underfloor ventilation system. Testing was completed after construction was mostly completed, but before furniture was moved into the spaces. The design of the walls between various spaces was based on the consulting acoustical engineer's experience and the client's desired level of noise isolation between various spaces. The client has requested that their name not be divulged.

1.1 OBJECTIVES

Our objectives included:

- Quantify the level of noise transfer between adjacent spaces with different wall types
- Compare the as-built wall performance with laboratory test data
- Document the background noise level in the various spaces
- Calculate the level of speech privacy between adjacent private offices
- Predict the level of occupant dissatisfaction with regards to speech privacy
- Assess the effectiveness of an underfloor acoustical septum
- Determine items for future study and analysis

2.0 ACOUSTICAL FEATURES

The tested spaces were in a commercial office building designed for a multimedia company. Charles M. Salter Associates (CSA) was hired to provide acoustical input for room acoustics and sound isolation between spaces.

The office spaces had differing acoustical requirements, which can be grouped into the following broad categories:

1. Standard office next to standard office or executive office next to open plan office where "normal speech" privacy was the intended goal

2. Between adjacent executive offices where "confidential speech" privacy was required

3. Audio editing suites

4. Audio playback suites

5. Audio recording suites where inaudibility was required

5. Audio playback suites with subwoofers next to audio editing suites

The following sections summarize the relevant construction and finish details at the tested spaces.

2.1 WALL TYPES

CSA recommended five main wall types for the various adjacencies; upgraded walls were specified between spaces requiring high levels of acoustical isolation. The following pages show details of the various wall constructions.

Wall type 1 was specified between standard offices where normal speech privacy was desired. Wall type 2 was specified between adjacent executive offices and/or conference rooms. These walls are illustrated below:

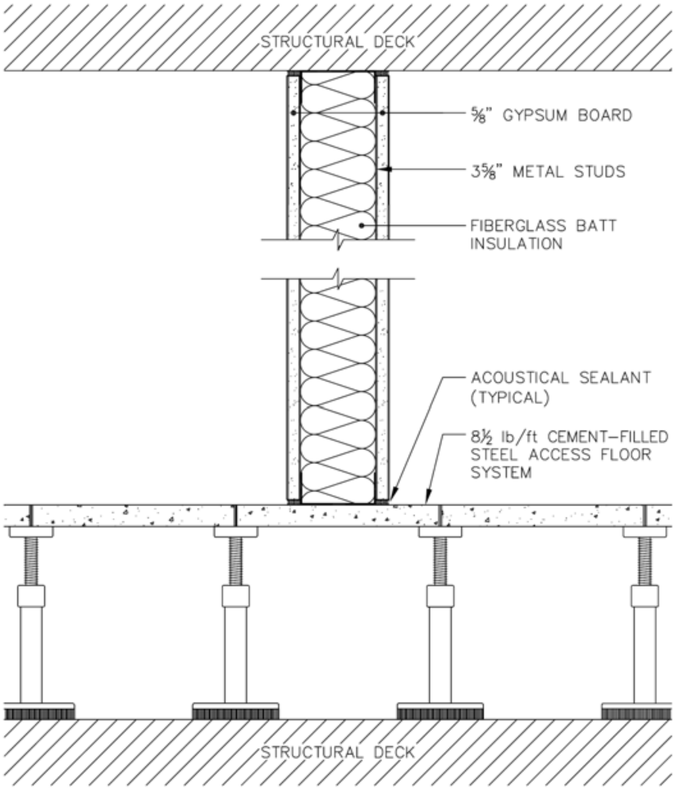


Figure 1. Wall Type 1 for Standard Offices

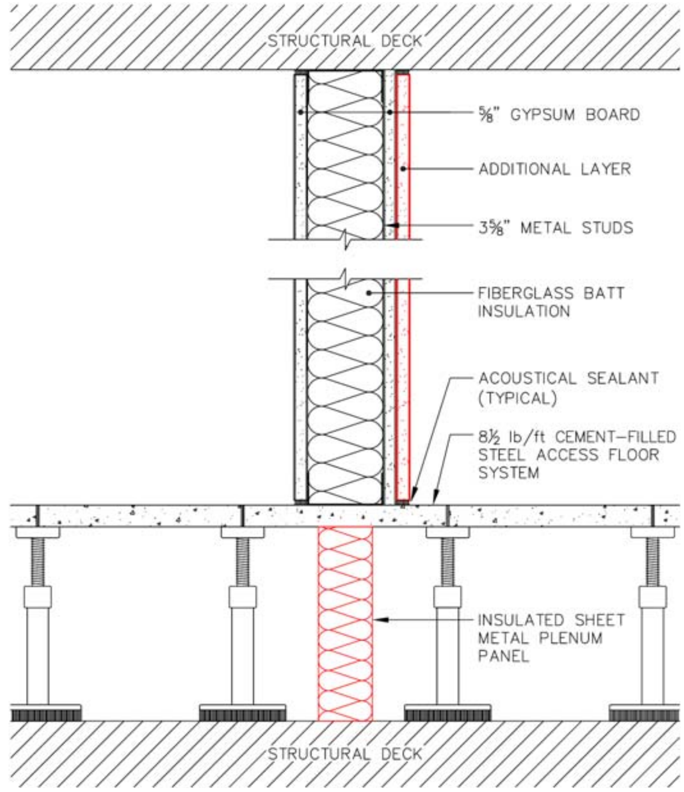


Figure 2. Wall Type 2 for Exec. Offices & Conf. Rooms

Wall type 3 was specified between audio editing and audio playback suites, and wall type 4 was specified between audio presentation rooms with subwoofers. These wall types are illustrated below:

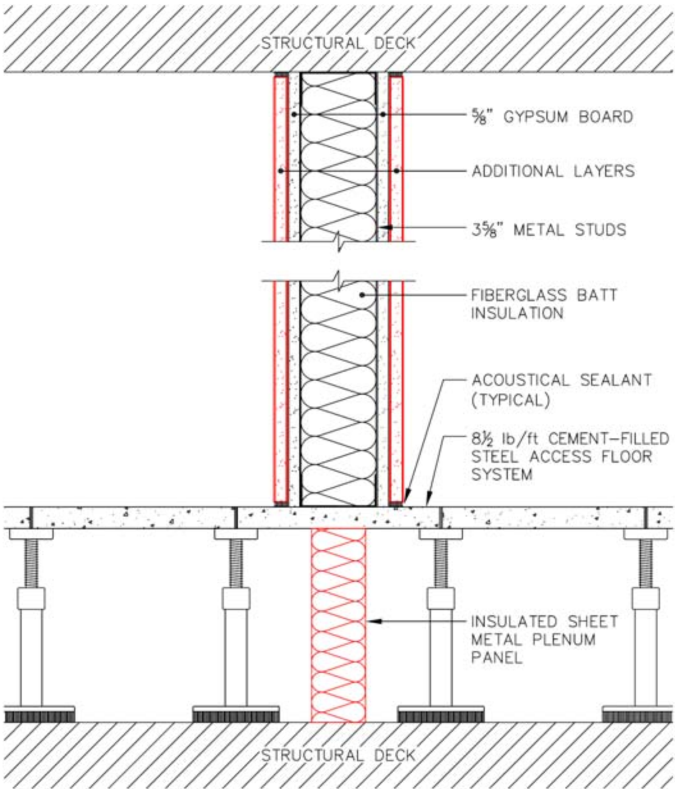


Figure 3. Wall Type 3 for Audio Editing & Playback Suites

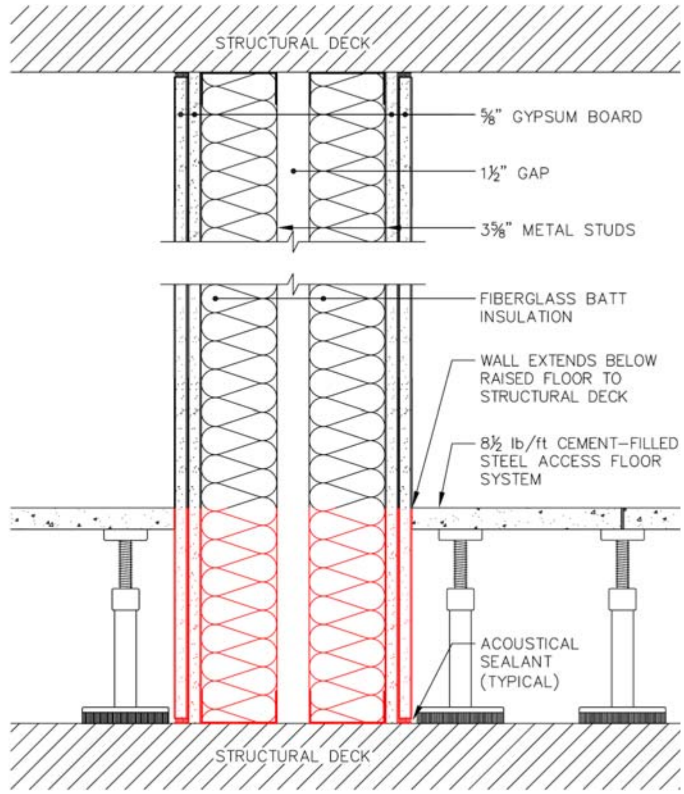


Figure 4. Wall Type 4 for Audio Presentation Rooms

Wall type 5 was specified to accommodate a structural column in the middle of the wall.

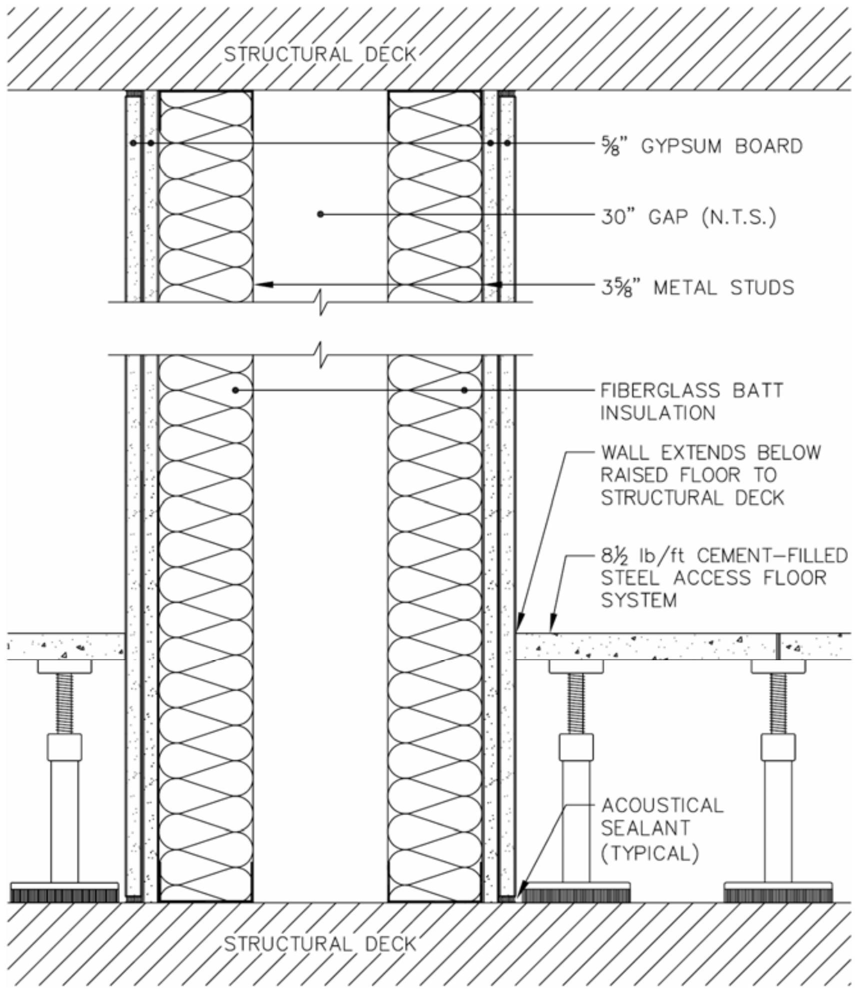


Figure 5. Wall Type 5 at Structural Column

2.2 CEILING

The ceilings at the tested spaces were primarily suspended acoustical tile ceiling "clouds"; however there were some areas of exposed concrete. The photograph to the right illustrates this condition.

The area above the suspended acoustical tile ceiling in open plan areas was used as the return air plenum for the HVAC system. Noise can travel from one space to another through the ceiling return air grilles compromising the acoustical performance of the shared wall.

In order to minimize this potential flanking path, offset return air transfer grilles were located above the doors of standard and executive private offices. Lined return transfer ducts were used at conference rooms, audio edit suites, and audio playback suites.

Figure 6. Acoustical Tile Ceiling Cloud

Figure 7. Offset Return Air at Private Office

Figure 8. Offset Return Air at Open Plan

2.3 FLOOR

The raised floor consisted of Tate Concore 1250 Posilock carpeted floor panels that have a surface density of 8.5 pounds per square foot. Conditioned supply air was provided via the underfloor air distribution system. At the perimeter spaces, ducted discharge grilles were located in the raised floor near the exterior façade of the building at all spaces except for the audio edit rooms. Fan-powered terminal boxes located in the floor plenum supplied these ducted discharge grilles. At the interior, open-plan spaces, unducted swirl diffusers were installed at the raised floor.

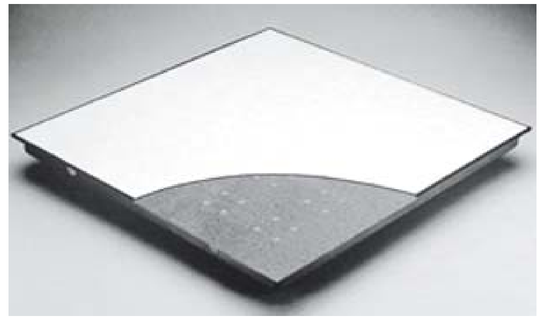


Figure 9. Tate Concore Floor Panel

The audio edit rooms incorporated a ducted supply to maintain positive pressure in the floor plenum of these rooms. The acoustical septum, which is described below, effectively blocked off the floor plenum of the audio edit room from the adjacent spaces; the ducted supply penetrated the septum to supply conditioned air in the audio edit rooms.

Figure 10. Tate Concore Floor Panel

There was concern that the open floor plenum could provide a flanking path and allow sound to travel between adjacent spaces via the open floor plenum. In order to reduce this flanking path, an acoustical septum was used in the floor plenum under the demising wall between executive private offices, conference rooms, audio editing, and audio playback suites. These acoustical septums were fabricated from sheet metal and fiberglass insulation. In order to provide an acoustical seal, metal "fingers" were fabricated at the top of septum which, when pushed into floor panel coffers, formed an acoustical seal at the septum and floor panel. Figure 11 shows pictures of an installed septum and Figure 12 shows a sample floor plan indicating where the septum was installed.

Figure 11. Installation of Acoustical Septum. The metal fingers at the top of the septum were later pushed into floor panel coffers, forming an acoustical seal at the septum and floor panel.

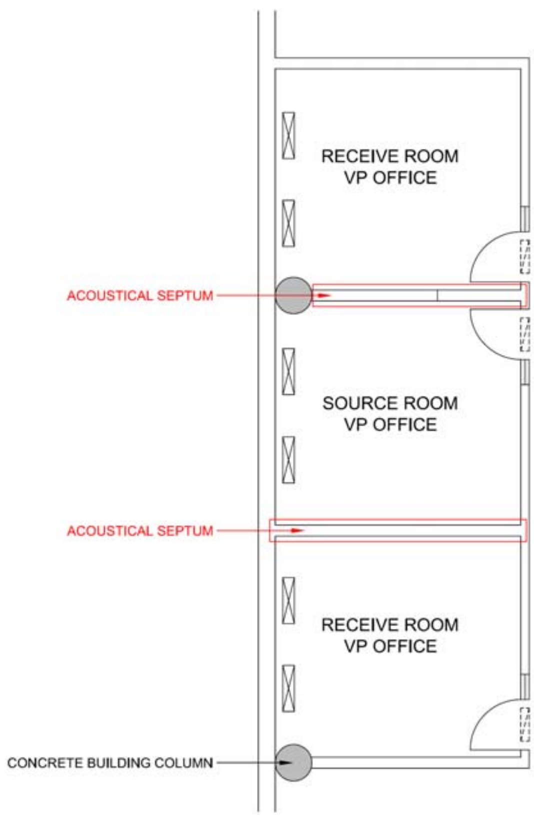


Figure 12. Sample Floor Plan Indicating Acoustical Septum Location

3.0 ACOUSTICAL TESTING

In order to predict the level of speech privacy between the various spaces, 17 sets of acoustical tests were performed. Both the noise isolation performance of the shared wall and the receive room background noise level was measured so that the predicted speech privacy level and occupant dissatisfaction rate could be calculated.

3.1 TESTING PROCEDURE

In order to quantify the level of sound transmission between adjacent spaces, a loudspeaker is set up in the source room and pink noise is generated at high sound levels. Calibrated recordings are then made in the source room and the adjacent receive room. The loudspeaker is then shut off and the background noise level in the receive room is recorded.

The acoustical testing was performed in accordance with the following relevant standards and protocols:

- ASTM E336 “Field Measurement of Sound Insulation in Buildings
- General Services Administration (GSA) Workplace 20•20 testing protocol for speech privacy calculation in private offices (references ASTM E1330)

The source sound level, received sound level, and background noise level were recorded onto digital audio tape (DAT); all instrumentation used was Type 1 precision under ANSI S1.4. The tape-recorded data was later analyzed to measure the sound pressure levels in 1/3-octave band levels required as part of the testing protocol.

Figures 14 and 15 on the following page provide pictures of the acoustical testing process. Figures 16 and 17 show the process of testing for sound leaks at the entry doors and return air transfer grilles. This process allows us to determine whether flanking is compromising a wall’s noise reduction performance. We found that the return air transfer grilles were not a source of flanking, however the entry doors were.

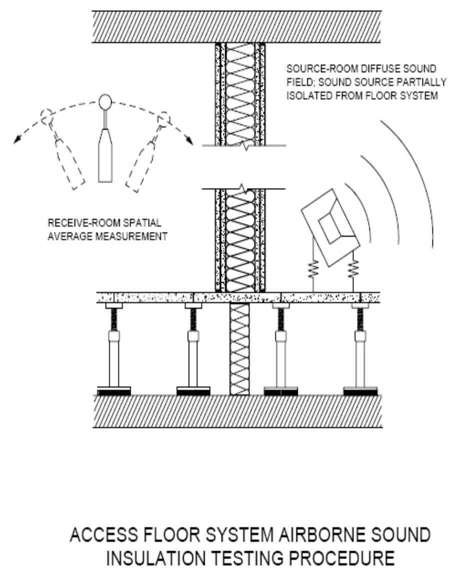


Figure 13. Acoustical Testing Method

3.2 ACOUSTICAL TESTING IMAGES

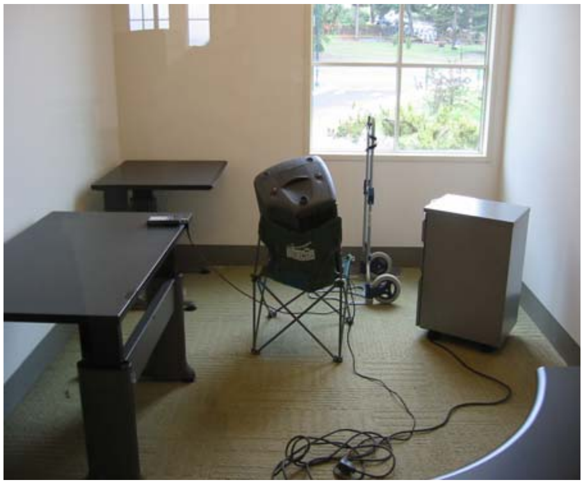


Figure 14. Source Room and Loudspeaker

Figure 15. Receive Room and Spatial Averaging

Figure 16. Sound Leak Assessment

Figure 17. Sound Leak Assessment

4.0 FIELD TEST FINDINGS

The following presents the findings of our study, organized by wall type. Each section provides a summary of the measurement data and speech privacy predictions are provided for adjacent standard offices and executive offices/conference rooms.

The predicted speech privacy level is based on the measured noise reduction performance of the shared wall, the measured background noise level in the receive room, and the sound pressure level of a “normal” voice as defined in ASTM E1130.

The measured noise reduction of the walls was corrected upward by three decibels to account for the unfurnished condition of the receive rooms; this corrected noise reduction is compared to the laboratory test data for each assembly.

Acoustical terms and an explanation of the speech privacy calculation method is contained in Section 7.0.

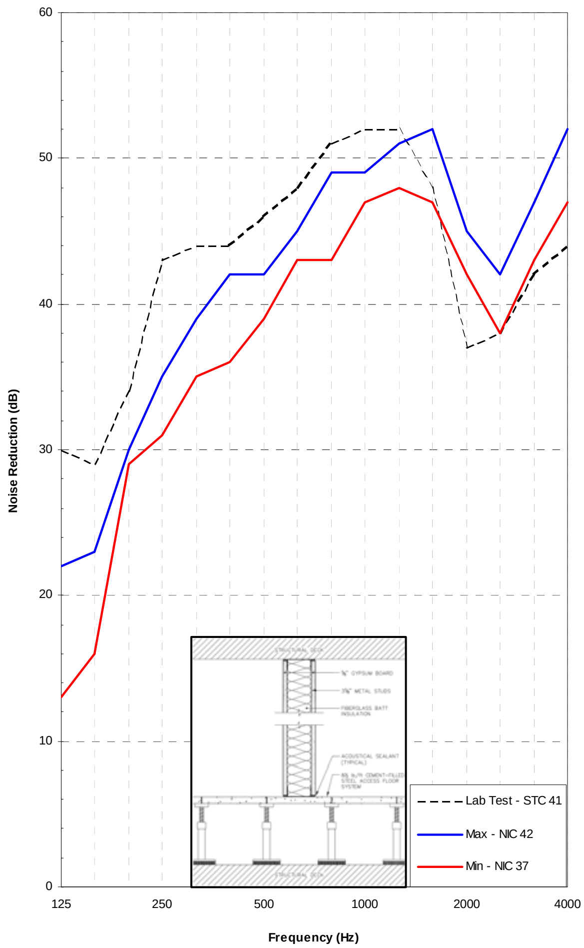
4.1 STANDARD OFFICE WALL

Wall type 1 achieved a typical sound isolation rating of NIC 40 with a range of NIC 37 to 42. Figure 18 on the following page graphs the minimum and maximum noise reduction performance of the five tested walls; the United States Gypsum Board Association laboratory test (#810518) for this wall assembly is also plotted to allow for a comparison of the field test results to laboratory test results. The blue line on the graph shows the highest measured noise reduction for the five tests whereas the red line shows the lowest measured noise reduction for the five tests. The dashed line shows the laboratory test results for this wall type.

The laboratory performance of wall type 1 is STC 41, which is roughly equivalent to an NIC rating of 41. A graph of the noise reduction performance for each of the five tested walls is included in Section 6.0.

Figure 18. Wall Type 1:

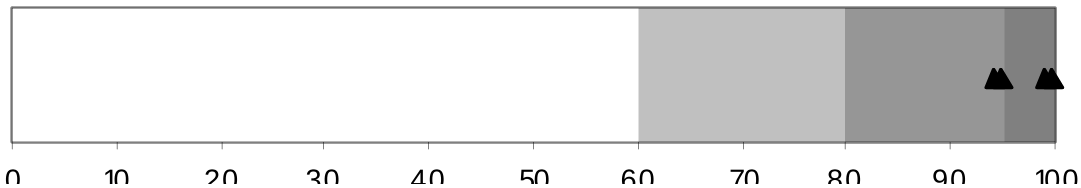
Min/Max Noise Reduction of Five Tests with Lab Comparison



Background noise levels in the receive rooms ranged from NC 31 to 38; the typical NC level measured was NC 36. ASHRAE recommends a background noise level of NC 35 for standard offices. These background noise levels, in conjunction with the noise reduction performance of the shared walls, were used to calculate the predicted speech privacy level between adjacent office spaces.

The predicted speech privacy levels are described in terms of the Privacy Index metric, which is a single number rating between 0 and 100, with 95 to 100 signifying "confidential" speech privacy. This privacy index number is then used to calculate the predicted level of occupant dissatisfaction. An explanation of these prediction methods is provided in Section 7.0. Figure 19 below illustrates the predicted speech privacy levels for the five tested assemblies; Table 1 below the figure provides detailed speech privacy predictions and occupant dissatisfaction rates for each measured office pair.

Figure 19. Predicted Speech Privacy Levels for Standard Office Walls



Privacy Level	Privacy Index Range
Unacceptable	0 to 60
Marginal	60 to 80
Normal	80 to 95
Confidential	96 to 100

Table 1. Predicted Speech Privacy Levels and Predicted Occupant Dissatisfaction

Test Number	Privacy Index	Occupant Dissatisfaction
1	96	1%
2	99	0%
3	96	0%
4	95	1%
5	100	0%

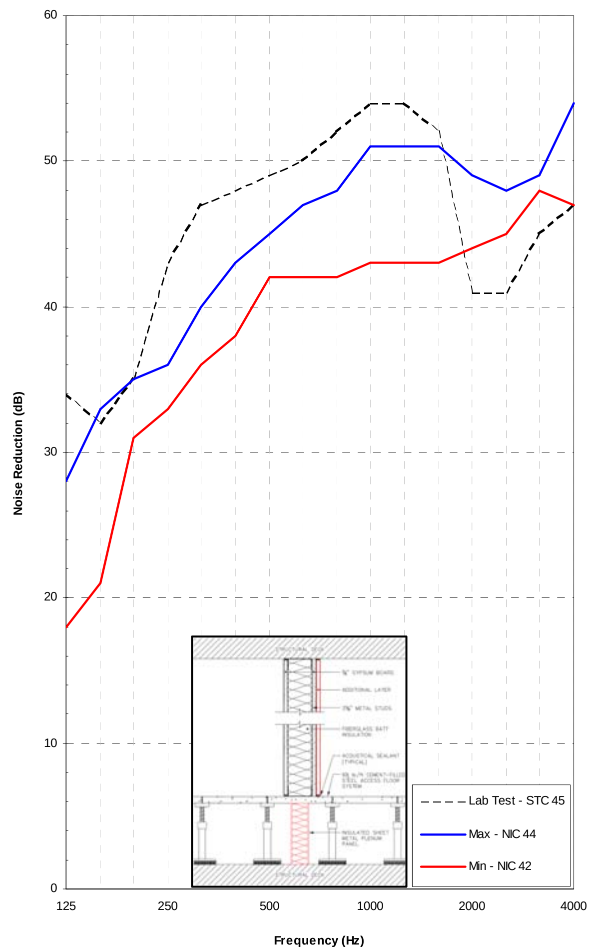
4.2 EXECUTIVE OFFICES AND CONFERENCE ROOMS WITH SEPTUM

Wall Type 2 achieved a typical sound isolation rating of NIC 43 with a range of NIC 42 to 44. Figure 20 on the following page graphs the minimum and maximum noise reduction performance of the four tested walls; the United States Gypsum Board Association laboratory test (#811007) for this wall assembly is also plotted to allow for a comparison of the field test results to laboratory test results. The blue line on the graph shows the highest measured noise reduction for the four tests whereas the red line shows the lowest measured noise reduction for the four tests. The dashed line shows the laboratory test results for this wall type.

The laboratory performance of the tested wall is STC 45, which is roughly equivalent to an NIC rating of 45. The measured walls performed nearly as well as the laboratory-tested wall. A graph of the noise reduction performance for each of the four tested walls is included in Section 6.0.

Figure 20. Wall Type 2:

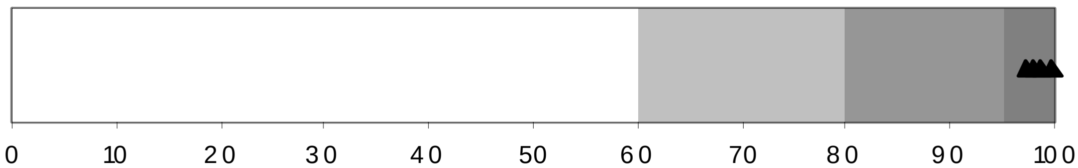
Min/Max Noise Reduction of Four Tests with Lab Comparison



Background noise levels in the receive rooms ranged from NC 34 to 38; the typical NC level measured was NC 36. ASHRAE recommends a background noise level of NC 30 for executive offices and conference rooms. These background noise levels, in conjunction with the noise reduction performance of the shared walls, were used to calculate the predicted speech privacy level between adjacent executive offices and conference rooms.

The predicted speech privacy levels are described in terms of the Privacy Index metric, which is a single number rating between 0 and 100, with 95 to 100 signifying "confidential" speech privacy. This privacy index number can then be used to calculate the predicted level of occupant dissatisfaction. An explanation of these prediction methods is provided in Section 7.0. Figure 21 below illustrates the predicted speech privacy levels for the four tested assemblies; Table 2 below the figure provides detailed speech privacy predictions and occupant dissatisfaction rates for each measured office pair.

Figure 21. Predicted Speech Privacy Levels for Executive Office/Conference Room Walls



Privacy Level	Privacy Index Range
Unacceptable	0 to 60
Marginal	60 to 80
Normal	80 to 95
Confidential	96 to 100

Table 2. Predicted Speech Privacy Levels and Predicted Occupant Dissatisfaction

Test Number	Privacy Index	Occupant Dissatisfaction
1	100	0%
2	97	1%
3	98	0%
4	99	0%

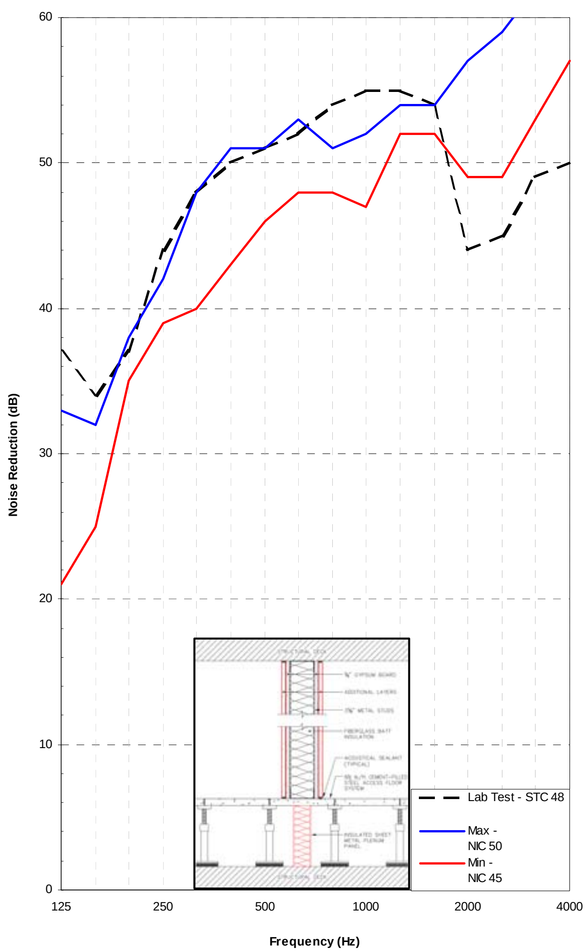
4.3 AUDIO EDITING SUITES

Wall type 3 achieved a typical sound isolation rating of NIC 46 with a range of NIC 45 to 50. Figure 22 on the following page graphs the minimum and maximum noise reduction performance of the three tested walls; the United States Gypsum Board Association laboratory test (#811006) for this wall assembly is also plotted to allow for a comparison of the field test results to laboratory test results. The blue line on the graph shows the highest measured noise reduction for the three tests whereas the red line shows the lowest measured noise reduction for the three tests. The dashed line shows the laboratory test results for this wall type.

The laboratory performance of the tested wall is STC 48, which is roughly equivalent to an NIC rating of 48. The measured walls performed nearly as well as the laboratory-tested wall. A graph of the noise reduction performance of each of the three tested walls is included in Section 6.0.

Figure 22. Wall Type 3:

Min/Max Noise Reduction of Three Tests with Lab Comparison

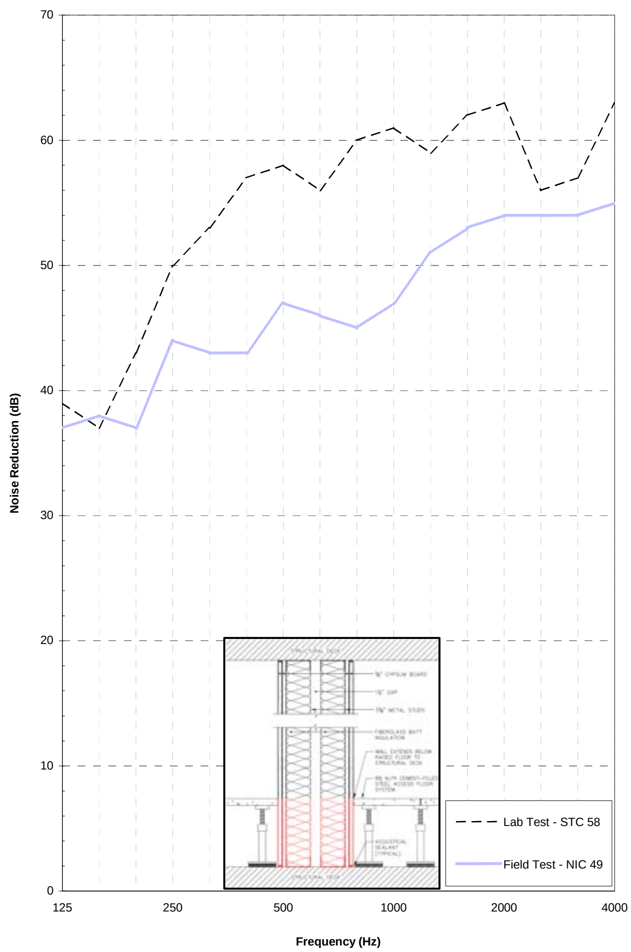


4.4 AUDIO PLAYBACK WITH SUBWOOFER AND AUDIO RECORDING SUITES

Wall type 4 achieved a sound isolation rating of NIC 49. Figure 23 on the following page graphs the noise reduction performance of the one tested walls; the United States Gypsum Board Association laboratory test (#750102) for this wall assembly is also plotted to allow for a comparison of the field test results to laboratory test results.

Figure 23. Wall Type 4:

Noise Reduction of Field Test with Lab Comparison



5.0 CONCLUSIONS

As can be seen from the data in the previous sections, the overall level of speech privacy between the various spaces tested meets normal privacy standards. The performance of wall type 1 in standard offices was, in general, a few points lower than the wall's laboratory performance with no raised floor. This lower performance could be due to flanking through the raised floor and floor plenum. Wall type 2, incorporating the acoustical septum, performed similar to the wall's laboratory performance with no raised floor. This seems to indicate that the acoustical septum may reduce noise transfer through the floor plenum since there was no real degradation in field performance versus laboratory performance for the wall that had the acoustical septum, while the wall without the septum performed lower in the field than in the laboratory. This may indicate that an acoustical septum may be warranted for spaces requiring high levels of speech confidentiality and/or noise reduction. The return air in both wall types 1 and 2 was handled with offset air transfer grilles on the corridor or open plan side of the offices, and had no effect on the testing results.

The spaces with full-height demising walls (wall types 3 and 4) provided a high level of noise reduction and these walls generally performed similar to the wall's laboratory performance.

This study represents acoustical measurements in one building with an underfloor ventilation system designed to meet the needs of a particular client. Other plenum layout conditions, floor constructions, wall choices, room sizes and design considerations may yield different results. Additional acoustical studies either conducted in the field or laboratory would be necessary to answer more generic questions with respect to the acoustical performance of underfloor ventilation systems.

6.0 APPENDIX – DETAILED ACOUSTICAL TESTING RESULTS

The following charts present the detailed acoustical testing results for the various wall types. Each chart contains the noise reduction values for each field test performed between spaces with the specified wall type. The laboratory noise reduction performance is also plotted and is shown with the black, dashed line.

Figure 24. Wall Type 1 at Standard Offices: Noise Reduction for Five Tests

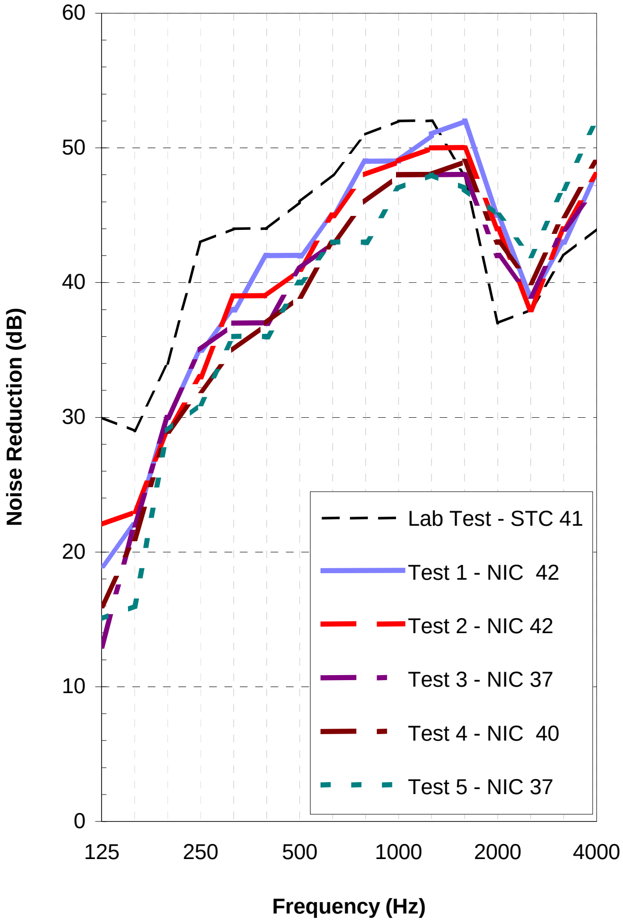


Figure 25. Wall Type 2 at Executive Office/Conference Rooms: Noise Reduction for Four Tests

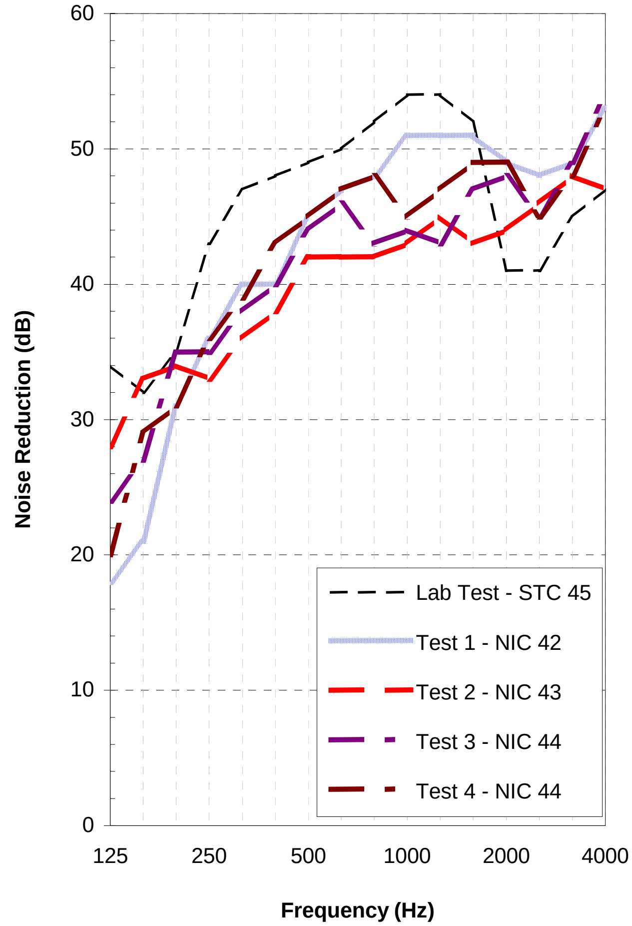
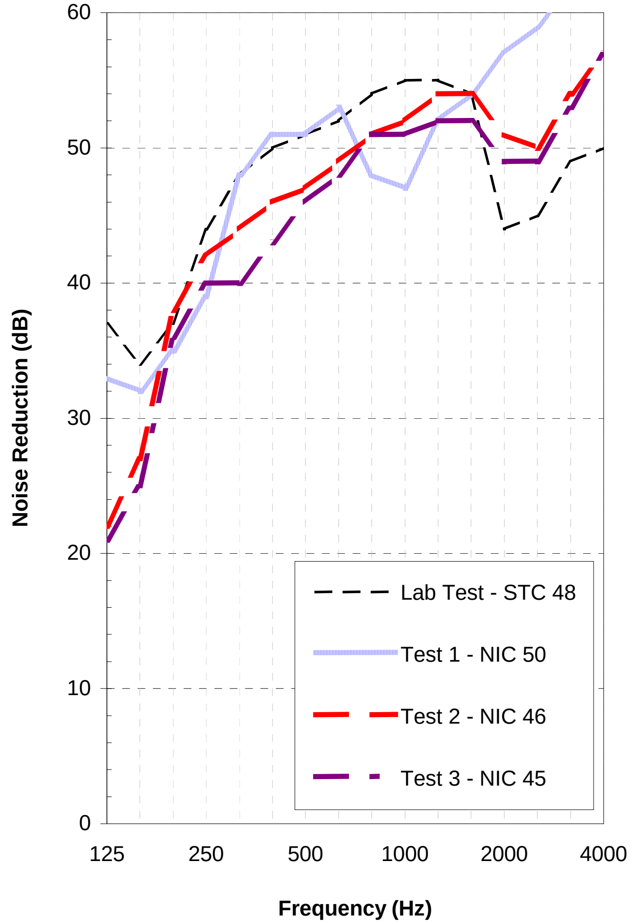


Figure 26. Wall Type 3 at Audio Editing Suites:

Noise Reduction for Three Tests



7.0 SPEECH PRIVACY CALCULATION AND ACOUSTICAL TERMS

The following provides an explanation of the speech privacy prediction calculation and provides definitions for some of the acoustical terms used in this report.

7.1 SPEECH PRIVACY CALCULATION

In order to predict the level of speech privacy between spaces, calculations are made using the following inputs: ASTM defined normal voice levels, the measured noise reduction of the intervening wall, and the background noise level measured in the receive space. The section below provides a snapshot of a speech privacy calculation worksheet and provides a brief overview of the calculation process, column by column.

A: The frequency range of interest (200 – 5000 Hz).

B: Loudspeaker noise level in the source room

C: Measured sound level in the receive room

D: The noise reduction provided by the wall is obtained by subtracting column B minus column C

E: Normal speech level as defined by ASTM E 1330

F: The intruding speech level is calculated by subtracting column E minus column D

G: The measured minimum background noise level in the receive room

H: The signal-to-noise level is calculated by subtracting column F minus column G

I: Importance of frequency band for speech interference, as defined by ASTM E 1330

J: Multiplying column H by column I yields the privacy index

A	B	C	D	E	F	G	H	I	J
Frequency (Hz)	Source @ 3-ft	Source @ Listener	Noise Reduction (B-C)	NORMAL Voice ASTM	Intruding Speech @ Listener Location (E-D)	Background Noise @ Listener (L_{min})	Signal to Noise (F-G)	Weighting Factor	AI Contribution (H2*I)
200	82.9	55.6	27.3	60.0	32.7	39.5	0.0	0.0004	0.00000
250	85.1	52.7	32.4	64.0	31.6	39.6	0.0	0.0010	0.00000
315	82.5	47.1	35.4	63.0	27.6	32.6	0.0	0.0010	0.00000
400	84.1	44.9	39.2	65.0	25.8	32.8	0.0	0.0014	0.00000
500	81.8	43.0	38.8	66.0	27.2	31.8	0.0	0.0014	0.00000
630	82.1	40.3	41.8	64.0	22.2	27.5	0.0	0.0020	0.00000
800	81.7	36.0	45.7	58.0	12.3	25.7	0.0	0.0020	0.00000
1000	78.7	32.9	45.8	58.0	12.2	23.4	0.0	0.0024	0.00000
1250	80	32.0	48.0	59.0	11.0	18.5	0.0	0.0030	0.00000
1600	78.5	29.9	48.6	56.0	7.4	14.3	0.0	0.0037	0.00000
2000	78	36.1	41.9	52.0	10.1	12.3	0.0	0.0038	0.00000
2500	78.6	42.6	36.0	53.0	17.0	10.1	6.9	0.0034	0.02346
3150	78.8	38.9	39.9	53.0	13.1	9.5	3.6	0.0034	0.01224
4000	78.6	33.5	45.1	50.0	4.9	8.9	0.0	0.0024	0.00000
5000	74.7	27.5	47.2	46.0	-1.2	9.3	0.0	0.0020	0.00000
dBA	90.7	51.6	39.1	69.5	30.5	36.8			
								Privacy Index	96
								Predicted Occupant Dissatisfaction	1%

7.1 TERMS

Noise Isolation Class (NIC) - A single-number rating derived from measured values of noise reduction. It provides an evaluation of the sound isolation between two enclosed spaces that are acoustically connected by one or more paths. Increasing NIC values correspond to improved noise isolation.

Sound Transmission Class (STC) - A single-figure rating used to rate the sound insulation properties of building partitions. The STC rating is derived from laboratory measurements of a particular building element and as such is representative of the maximum sound insulation.

Noise Criterion (NC) - A single number rating describing a continuous noise in terms of level and spectrum. NC is typically used to rate the subjective loudness of ventilation equipment noise indoors.

Flanking Transmission – The transmission of airborne sound from a source room to an adjacent receive room by a path other than the common partition