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Modeling Computer Data Center Noise in Odeon

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Abstract

Modern computer data centers are facing an increasing number of rack servers within rooms that contain employee desks and workstations. As the quantity of servers increases, the noise levels approach and can potentially exceed the Occupational Safety and Health Administration's (OSHA) noise exposure level limits for employees. This set of computer simulations modeled rack servers using sound power and directivity data obtained from actual servers. Using ODEON, an acoustical modeling software package that utilizes ray tracing, sound pressure level distributions were calculated while adjusting the quantity of servers, position of servers, and absorption characteristics of the room's surfaces. The results confirmed that levels in the aisle ways of server rooms can reach or exceed the 85 dBA (re: 20μPa) OSHA Action Level. Furthermore, simulations involving moving the position of the servers in the room did not provide a viable option to reduce exposure levels within the vicinity of the server racks.

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Purpose

The purposes of this project were to conduct a study of ODEON modeling techniques and evaluate the sound pressure levels of data centers as it pertains to the noise exposure of employees. The quantity of servers, position of servers, and absorption characteristics of the enclosing room's surfaces were all varied to find trends in the sound levels of the work spaces.

Background Information

Excessive noise exposure in the workplace is governed by the Occupational Safety and Health Administration (OSHA) in order to prevent a variety of harmful, short-term and long-term negative effects on employees. The Administration's *Hearing Conservation Amendment* of 1983 requires that a mandatory hearing conservation program be implemented when the sound pressure level at a workplace meets 85 dBA (re: 20µPa). It is this action level that is the subject of concern by the Information Technology (IT) industry in regards to the modern data center.

As more computing power is required of corporations and institutions, the raw quantity of high performance computer servers has increased. The concomitant increase of noise sources within data centers results in higher levels of background noise and additional concern for employees who spend long periods of time in these workplaces. This trend towards expanding the number of servers throughout the IT industry represents a shift in practice and research, as they join the traditional manufacturing sector in possessing work environments that potentially exceed the OSHA action level.

The results of excessive noise exposure in the workplace can be grouped into short-term and long-term effects. The short-term effects are generally associated with interference of an employee's activities and include stress, decreased concentration, and impaired communication. The long-term effects include potential physiological damage such as hearing loss and decreased mental health. It is important to note that every individual responds differently to a noisy environment. In particular, it is possible for an employee to suffer from short-term effects and potentially long-term effects in environments where the background noise level is approaching but does not meet the OSHA action level [1].

Previous Research

The effect of excessive noise on people is an area of acoustics that has been and continues to be well researched. Various studies on the subject have been reviewed and published in professional journals ranging from the 1970's to present day. Dr. Geoff Leventhall provides a detailed review of past research in the paper "Review of Research on Low Frequency Noise and its Effects", published by the Department for Environment, Food and Rural Affairs in May 2003 [2].

In characterizing annoyance, Guski (1999) describes the result of excessive noise stimulus as causing activity interference and vegetative reactions [3]. Activity interference, such as interference of communication, recreation, and sleep, leads to annoyance and disturbance. Vegetative reactions include blood pressure changes and defensive reactions. When coupled together, these two reactions can lead to prolonged health complications.

Kyriakides and Leventhall (1977) conducted a study that investigated the effects of low frequency noise and its relationship to task performance [4]. Subjects were exposed to various conditions of noise, both in the audible and infrasonic range, and were asked to perform tasks that lasted 36 minutes in duration. The effects of infrasound included a decline in some tasks. Furthermore, performance continued to deteriorate as time was spent on these tasks. A separate study by Persson-Waye *et al* (1977) assessed the performance of employees in a simulated work environment when exposed to low frequency noise [5]. While exposed to low frequency noise, subjects experienced interference to tasks and cognitive demands. In addition, the interference tended to develop over time and subjects experienced changes in mood including a lowered feeling of pleasantness.

By monitoring the hormone cortisol secreted within the body, researchers can objectively quantify levels of stress experienced by test subjects. This method was implemented by Persson-Waye *et al* (2002) when a study of noise sensitive subjects performed work tasks while being exposed to low frequency noise [6]. Subjects that were sensitive to low frequency noise experienced higher levels of cortisol and had impaired performance. It was concluded that changes in cortisol levels as a result of low frequency noise exposure can have a negative influence in health.

In researching this topic, the authors found little published material regarding the noise control of rack servers and high tech data centers. In addition to the work of Dr. Matt Nobile [1], one paper was located in the 2007 Proceedings of the ASME InterPack Conference by Holahan and Elison entitled "Fan Laws for Rack Systems" [7]. This document addresses some mechanical and acoustical concerns of the design of cooling systems for rack servers.

Procedure

Modeling of a variety of data center configurations was done using ODEON v9.1, an acoustical modeling program that utilizes a hybrid technique of the image source method and ray tracing to perform calculations [8]. The image source method is based on Snell's law, where the angle of the incident sound wave will equal the angle of the reflected sound wave. To determine the reflection path, an imaginary source is drawn on the other side of the reflecting surface and a ray can be drawn to the receiver. This process can be continued as the sound wave reflects off the other surfaces in the room. The amount of sound that is reflected each time is reduced by the absorption coefficient of the surface. This method only works for specular reflections and is typically only used for the first few reflection orders, as the number of image sources grows exponentially as the reflection order increases. In addition, invalid image sources can also occur at higher reflection orders and can be difficult to detect.

The program switches entirely to the ray tracing method after a user-specified transition order of reflections (usually 2-3). A large number of rays or sound particles are sent out in all directions from a sound source, where the intensity of the sound rays depends on the source characteristics. Each ray hits a surface and either reflects in a specular manner according to Snell’s law or diffuse manner depending on the scattering coefficient of the surface. The intensity of the rays is reduced based on the absorption coefficients of the surfaces. This process continues until the ray has been completely absorbed or some other parameter has been set to truncate the calculation, such as the impulse response length. All rays which pass through the defined receiver location are recorded to obtain the impulse response.

ODEON does include an algorithm to partially model diffraction using reflector theory [4]. This theory predicts the amount of specular reflections from an object of limited area based on the basic dimensions of the surface, angle of incidence, and incident and reflected path-lengths. The scattering of sound due to the edge of the object is estimated to be 50%. Since the algorithm is based on many assumptions and it is difficult to model wave phenomena using geometrical acoustics, diffraction is not modeled exactly.

Several different variables were controlled in order to study the trends of noise produced by servers in data centers. These include varying the location and quantity of servers in the room as well as varying the absorptive properties of the surfaces that compose the environment.

First, a room was created that matched the dimensions and absorption characteristics of the data center model created by Nobile *et al* [1]. This was done for comparative purposes and to assess modeling techniques used in ODEON, as Nobile *et al*'s work was completed in CATT-Acoustics, another room acoustics modeling program. In this room, a single server with dimensions 1.5m x 0.79m and 2.0m tall was placed in the center of the workspace with its front doors facing along the long axis of the 10.97m x 7.92m x 3.05m room, as shown in Figure 1. Typical absorption coefficients for suspended acoustical ceiling tile, drywall walls, and a tile floor (Table 1) were assigned to the surfaces of the room and the room had an average reverberation time of 0.45 s. Sound power data for the server as well as directivity data for how an actual server propagates sound energy was obtained from Dr. Matthew Nobile.

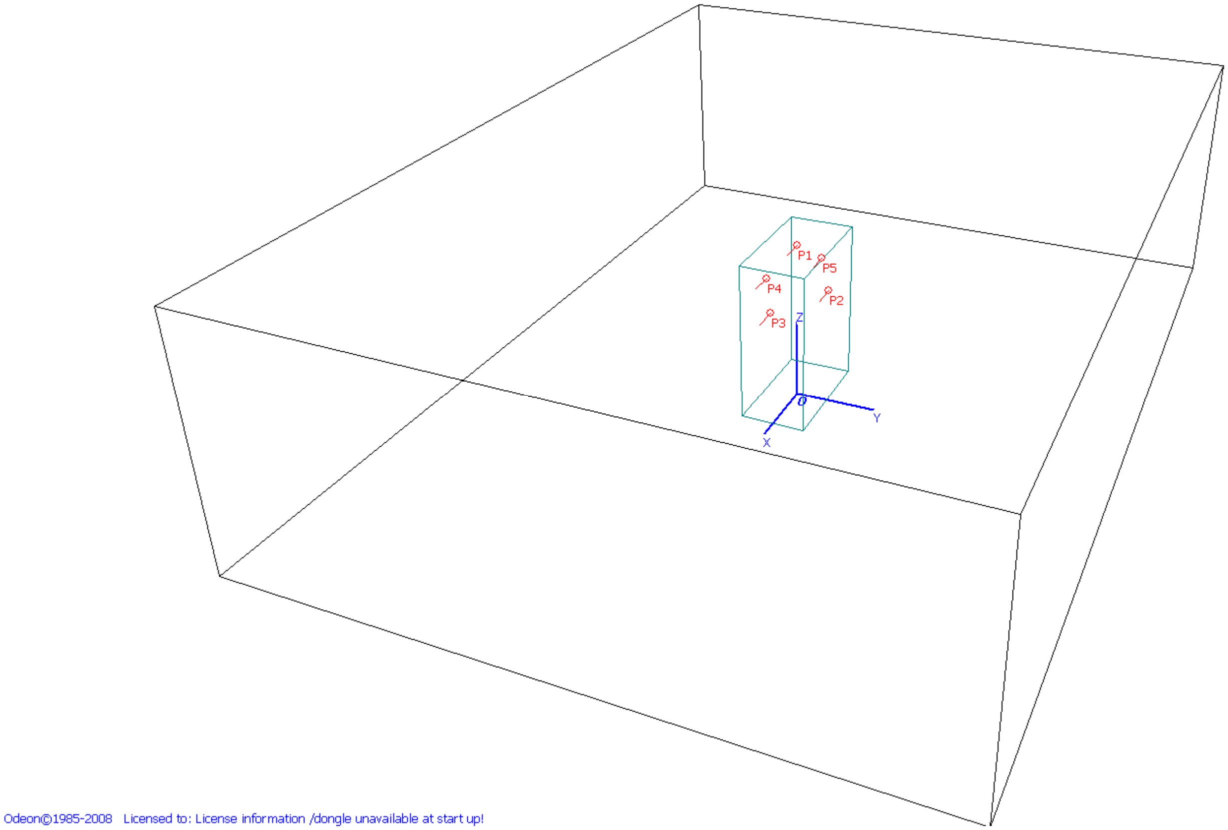


Figure 1 – Modeled Data Center with Single Server

Table 1 – Absorption Coefficients of Surfaces in Modeled Data Center

	Frequency (Absorption Coefficients)							
Surface	**63 Hz**	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**8000 Hz**
Acoustical Ceiling Tile	0.38	0.38	0.28	0.39	0.59	0.64	0.65	0.65
Drywall Walls	0.14	0.14	0.1	0.06	0.04	0.04	0.03	0.03
Tile Floor	0.02	0.02	0.03	0.03	0.03	0.03	0.02	0.02

Sound power data for rack servers in two conditions were obtained: (1) Condition EE, server covers off, and (2) Condition FF, server covers closed. These values are displayed Table 2. Figure 2 shows the source directivity characteristics of an IBM server in Condition EE.

Table 2 – Sound Power Levels of Rack Servers for Two Conditions

	Frequency (Sound Power Levels, dB re: 10^{-12} W)							
	63 Hz	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**8000 Hz**
Condition EE	70.94	78.37	80.80	84.30	80.86	79.48	73.97	70.80
Condition FF	70.40	75.55	77.53	79.20	71.69	69.30	64.77	62.53

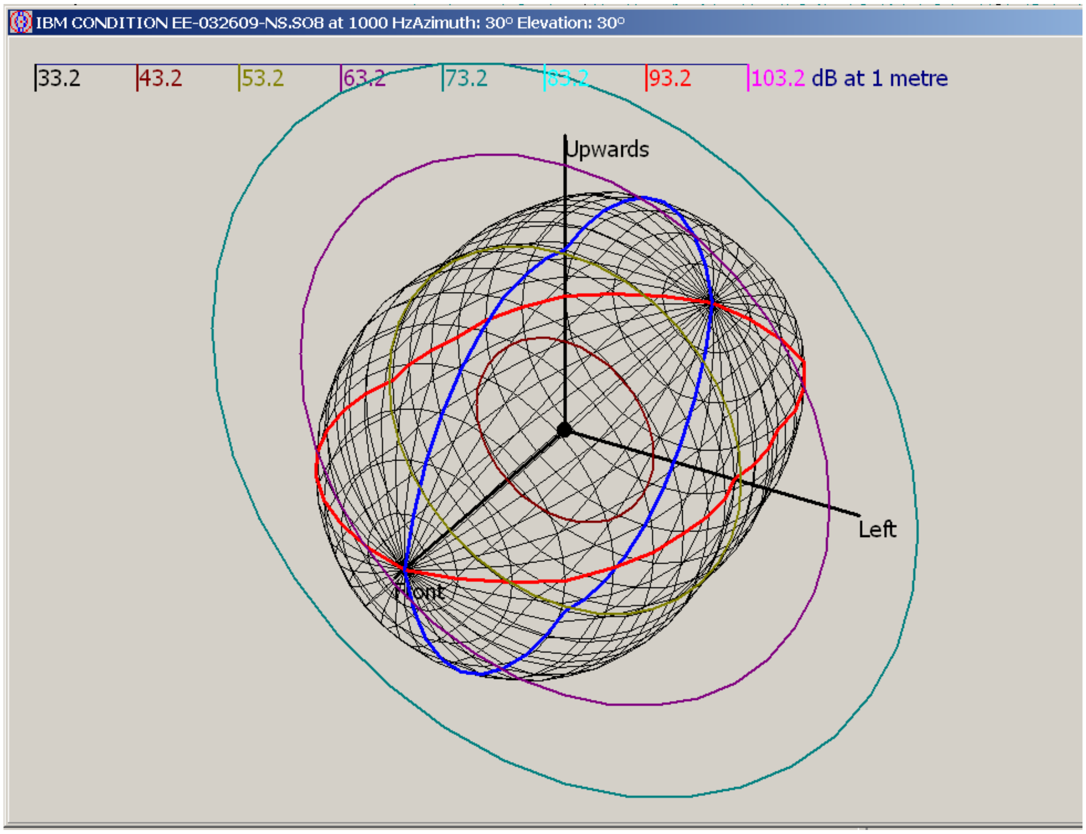


Figure 2 – Directivity File of Server Condition EE at 1000 Hz

In order to achieve reliable results, each model was test checked to make sure that no rays were leaving the room. Furthermore, a test was performed to confirm that a 6dB decrease of sound pressure level per doubling of distance was achieved in a fully absorptive room or under free field conditions. Also, a test was performed with fully reflective surfaces or under diffuse field conditions to confirm an even sound pressure level regardless of position. Three receivers were placed along the center line of the room and at distances of 1.0 m, 2.0m and 4.0m along the x-axis.

Table 3 – Diffuse and Free Field Initial Test Results

	Distance from Source		
	1.0m*	**2.0m***	**4.0m***
Free Field SPL (dB, re:20 μPa)	77.6	71.6	65.7
Diffuse Field SPL (dB, re: 20 μPa)	81.4	79.6	78.9

*Computed using the sum of octave bands from 500 Hz to 8000 Hz

Upon running early test simulations, the authors encountered a problem when trying to model the rack servers as sources within a three-dimensional rectangular geometry in ODEON. Originally, servers were defined as metal boxes with a single point source located in the center of the x-y plane and 1.5m off of the ground. The concept was that this single point source, equipped with directivity data measured from an actual server, would emanate rays of sound out from the server. These rays, upon reflecting off other surfaces, would return and reflect off the *outside* of the server rack cabinet as is expected in a real scenario. However, ODEON does not have the ability to allow sound rays to pass in one direction only, i.e. out of the server geometry, but not back into it.

To overcome this challenge, a solution was implemented that maintained the directivity and total sound power of the real server rack, but using a method that was possible to model in ODEON.

Instead of using a single point source in the center of the server, five point sources were used on the outer perimeter of the server box so that rays could travel freely in the room without becoming trapped within the cabinet. Figure 3 is an image of a single server with the five point sources located on the exterior of the cabinet.

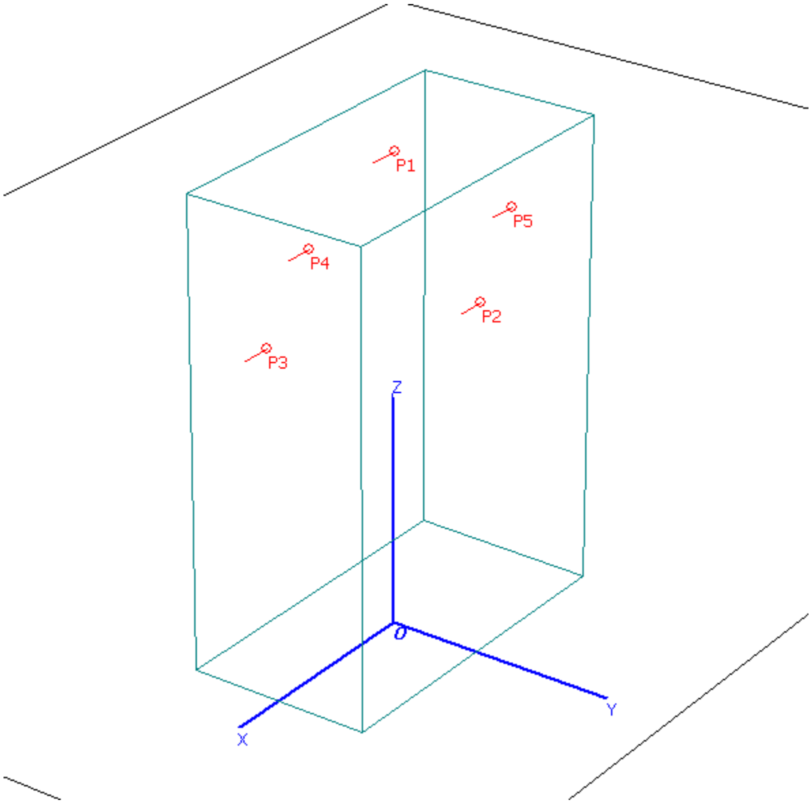
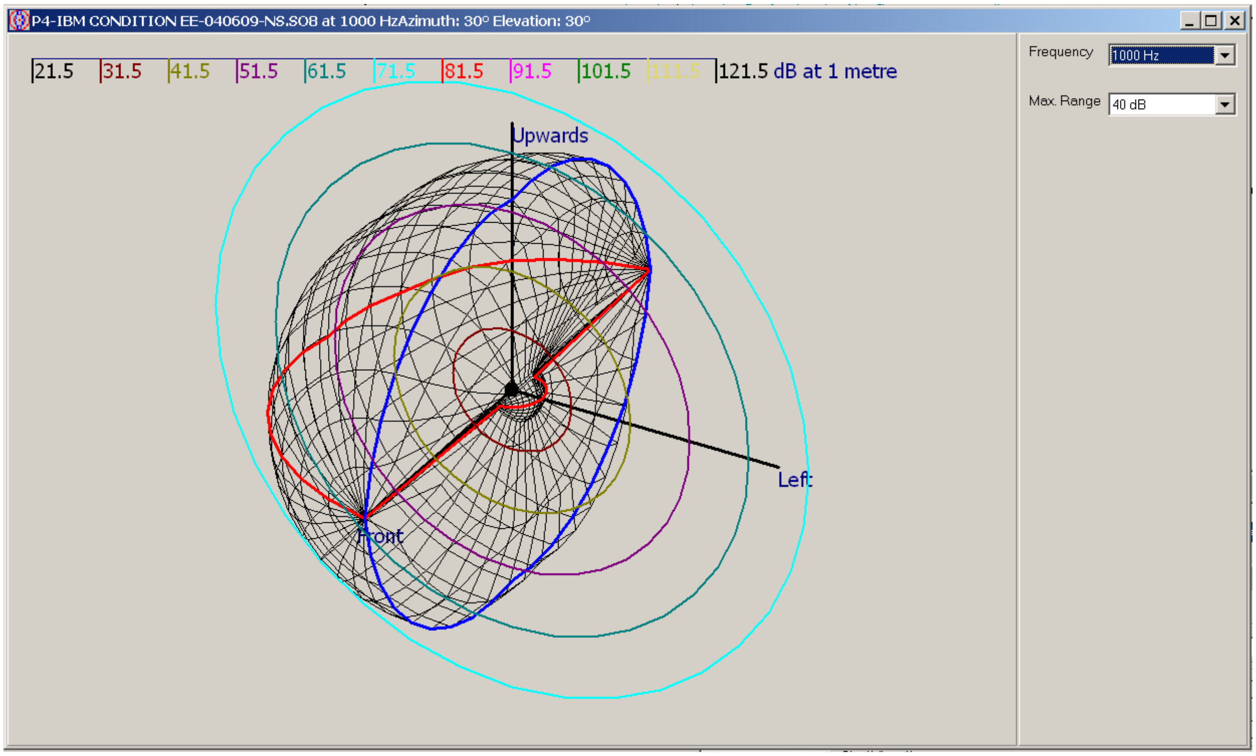


Figure 3 – Modeled Server with Five Point Sources

As a convention, all sources were directed in the same axis indicating the front of the server, thus allowing servers to be oriented in uniform directions. The directivity file was truncated into five unique files and assigned to each of the five point sources on the perimeter of the server. Calculations were performed to make sure that the total sound power of the five point sources was equivalent to the power of a single point source or actual computer rack. The sound power levels assigned to each of the five sources in the eight octave-bands, for both conditions, are summarized in Table 4. Figure 4 shows a directivity file for the server's right side point source.

Table 4 – Sound Power Levels of Each of Five Sources used to Model the Rack Servers for Two Conditions, Adjusted for Truncated Method

	Frequency (Sound Power Levels, dB re: 10^{-12} W)							
	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Condition EE	64.0	71.4	73.8	77.3	73.9	72.5	37.0	63.8
Condition FF	63.4	68.6	70.5	72.2	64.7	62.3	57.8	55.5



P4-IBM CONDITION EE-040609-NS.SO8 at 1000 HzAzimuth: 30° Elevation: 30°

Frequency 1000 Hz

Max. Range 40 dB

Figure 4 – Truncated Directivity for Source P4 of Condition EE in ODEON Server Model at 1000 Hz

Once testing confirmed that sound rays were emanating properly from the modeled server and were reflecting off room surfaces and server surfaces, several configurations were prepared for simulation. Three configurations were tested as summarized in Table 5. All configurations had the same typical absorption characteristics for the room surfaces with servers placed in the center of the room.

Table 5 – Server Quantity for Configurations A, C, and E

Configuration	Number of Servers
A	14
C	28
E	1

The following is an image of the arrangement of Configuration A with point sources displayed. The servers were positioned in two rows facing each other and creating an aisle in between them.

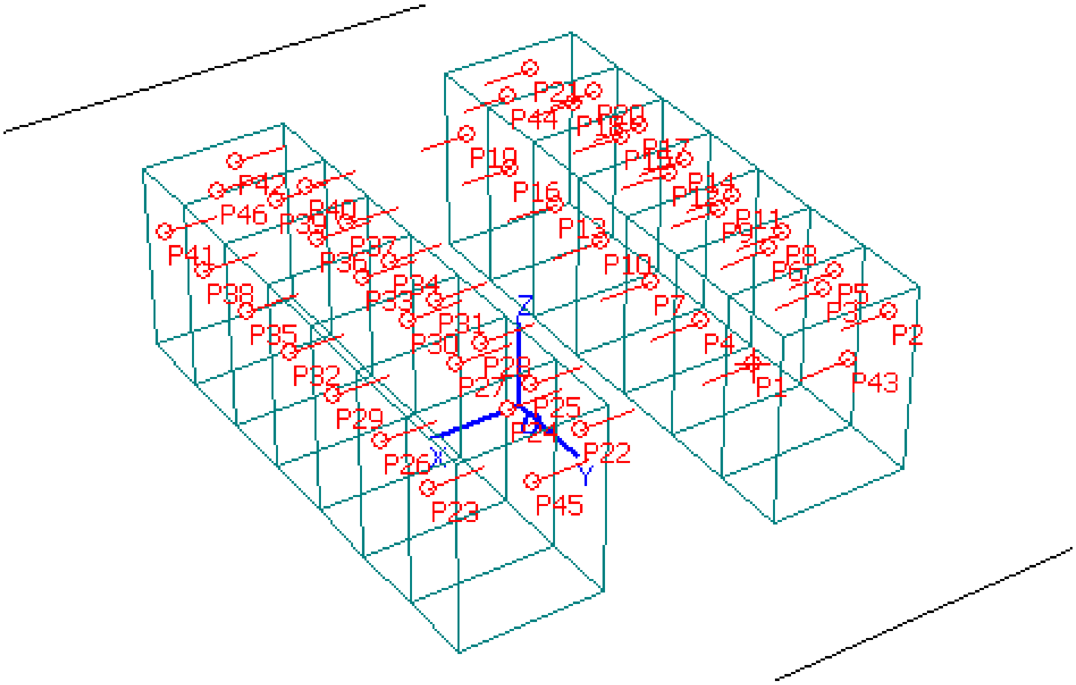
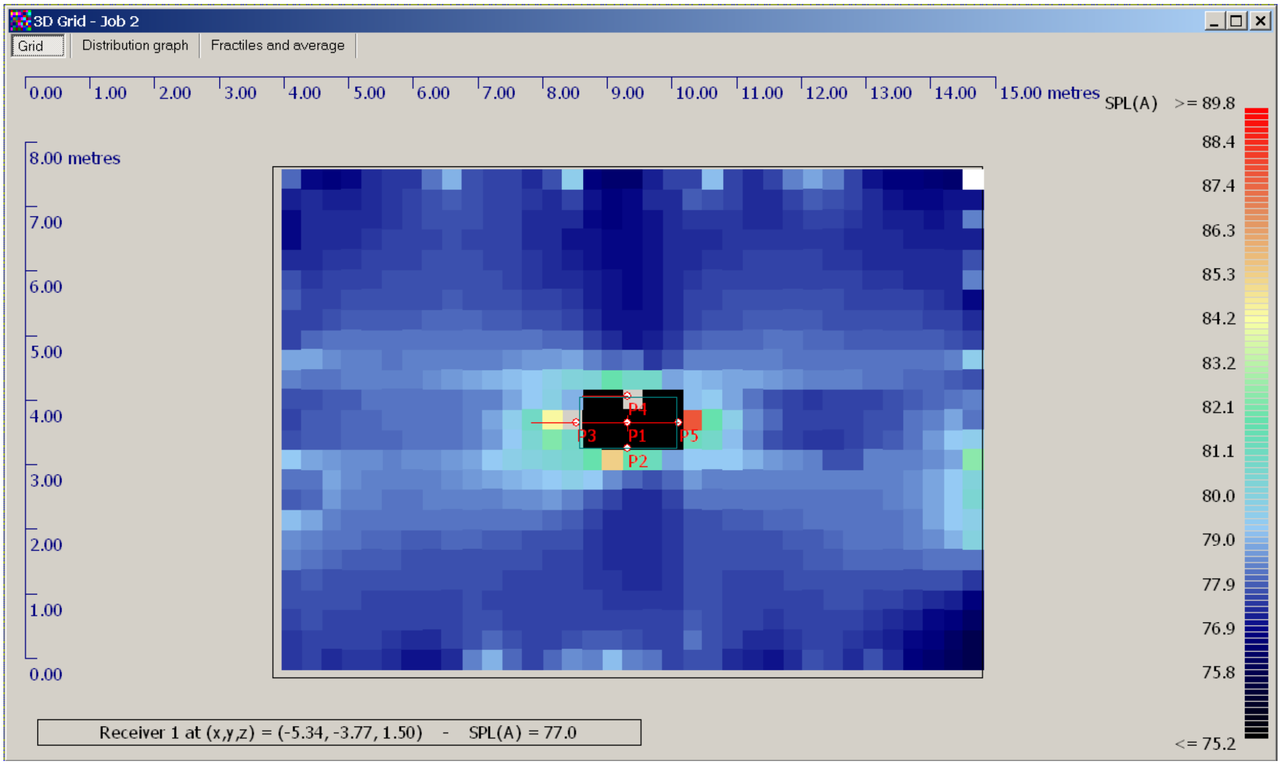


Figure 5 – Server Layout of Configuration A

Each simulation was performed using a 0.3m x 0.3m (approximately 1ft. x 1ft.) grid to calculate the A-weighted sound pressure level throughout the room. After Configurations A, C, and E had been tested, Configuration A was further examined by varying the absorption coefficients of the room's surfaces. Two more simulations of Configuration A, one with all surfaces at 0.01 absorption (highly reflective) and one with 0.99 absorption (highly absorptive) were utilized. While it is neither practical nor entirely possible to achieve these parameters in the real world, the authors wanted to discover what the theoretical range of background noise in the room generated by the servers as a function of room absorption. Lastly, the two rows of servers were repositioned in two different arrangements in the corner of the room in order to vary the path of sound to a potential receiver in the opposite corner. These final two positions, referred to as Configuration A2 and Configuration A3, were computed using both the highly reflective and highly absorptive surface conditions.

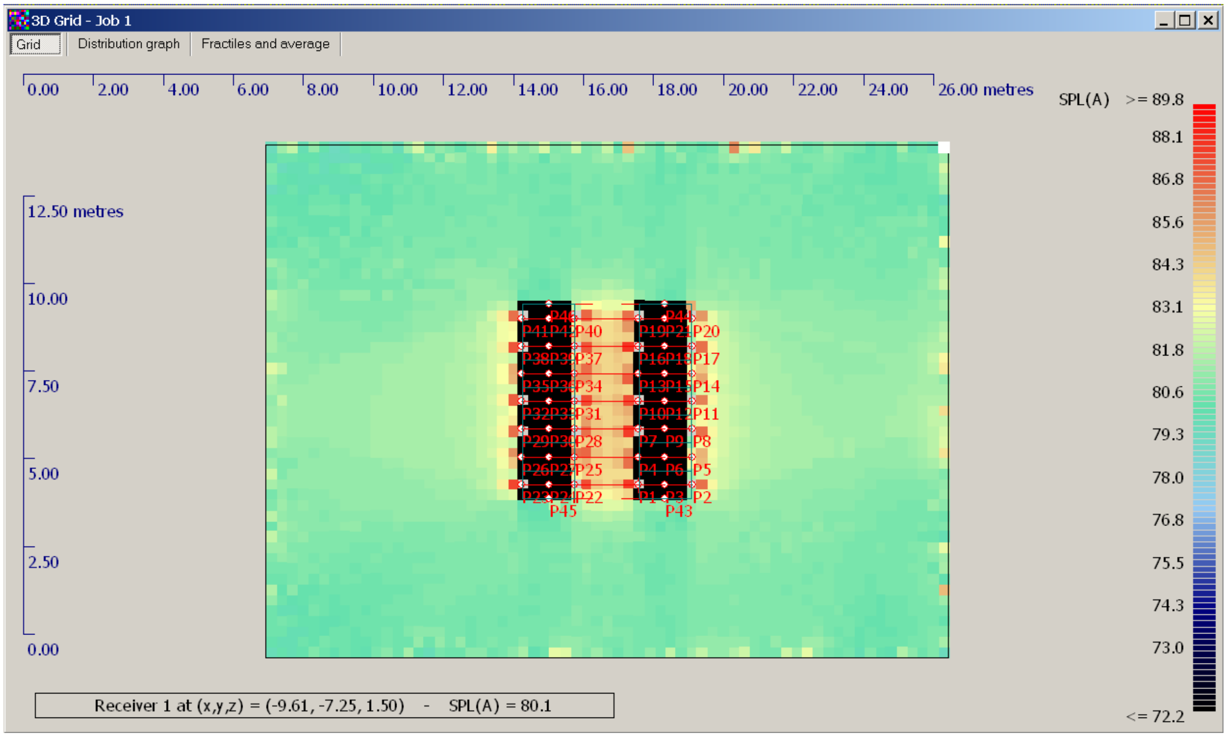
Results

Using typical absorption coefficients for the surfaces of the room, different quantities of servers were placed in the center of the room. The following are the resulting sound pressure level contours of noise produced by the servers.



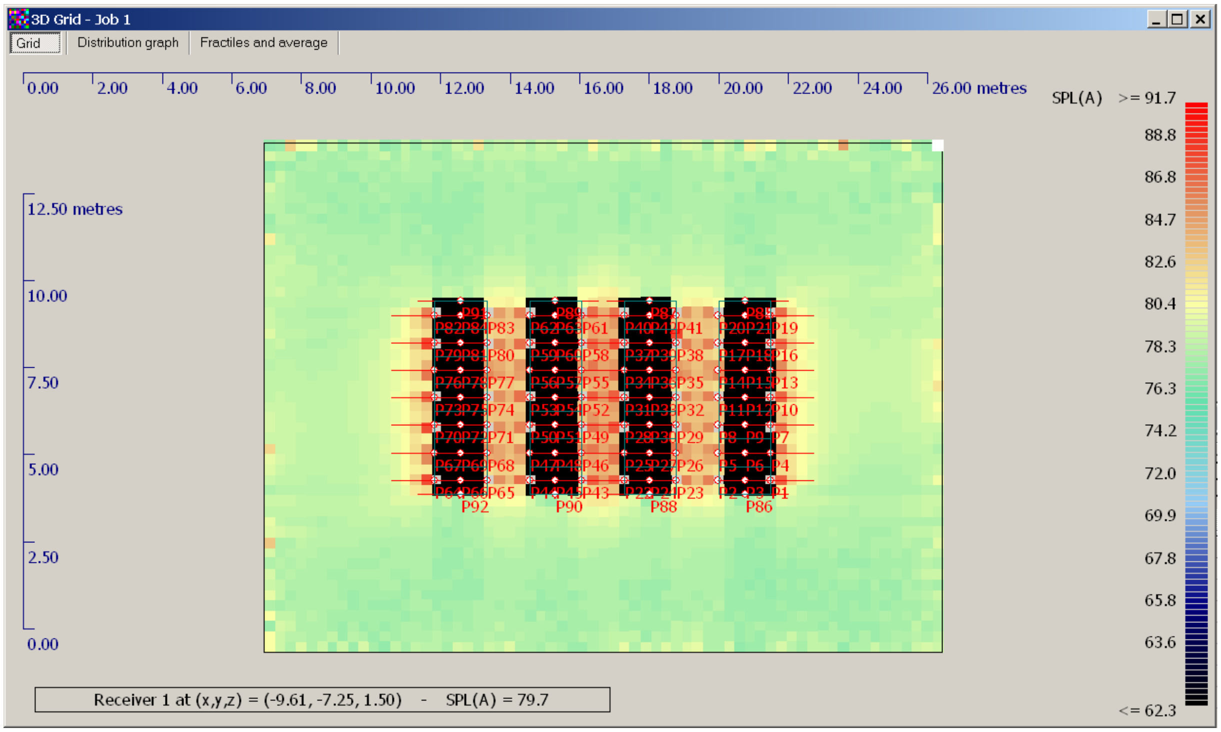
Receiver 1 at (x,y,z) = (-5.34, -3.77, 1.50) - SPL(A) = 77.0

Figure 6 – Sound Pressure Levels (A-weighted, dB re: 20μPa) of Configuration E



Receiver 1 at (x,y,z) = (-9.61, -7.25, 1.50) - SPL(A) = 80.1

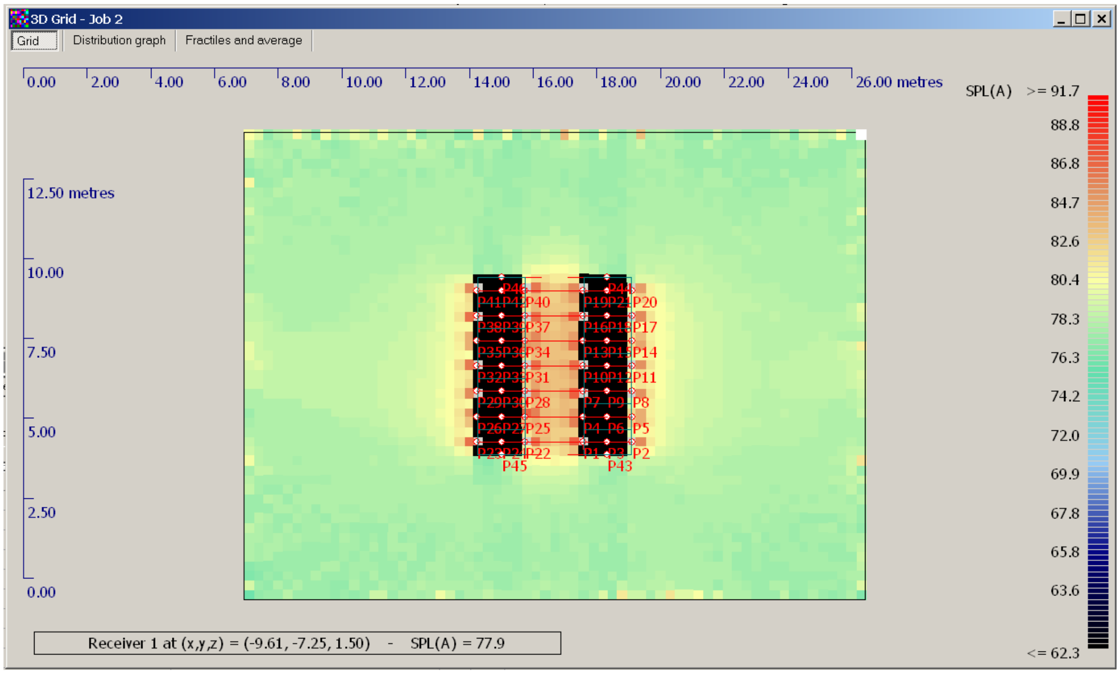
Figure 7 – Sound Pressure Levels (A-weighted, dB re: 20µPa) of Configuration A



Receiver 1 at (x,y,z) = (-9.61, -7.25, 1.50) - SPL(A) = 79.7

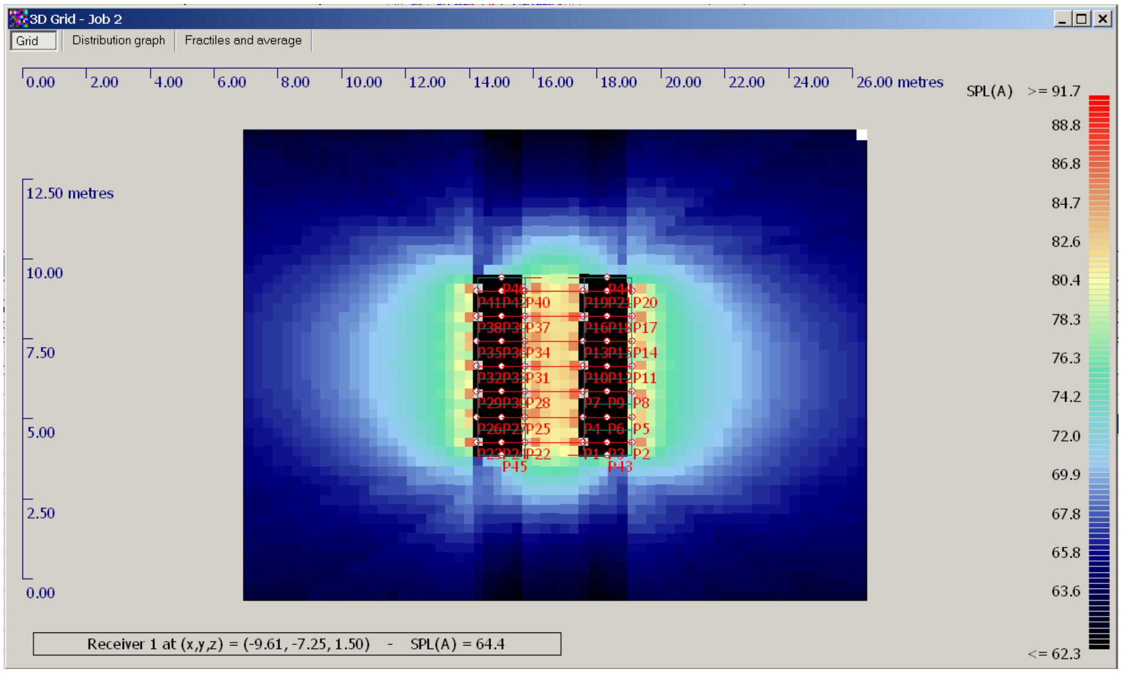
Figure 8 – Sound Pressure Levels (A-weighted, dB re: 20µPa) of Configuration C

After these simulations were completed, further investigation of Configuration A was conducted by varying the absorption coefficients. Figures 9 and 10 show the sound pressure level contour of Configuration A with highly reflective and highly absorptive room surfaces, respectively.



Receiver 1 at (x,y,z) = (-9.61, -7.25, 1.50) - SPL(A) = 77.9

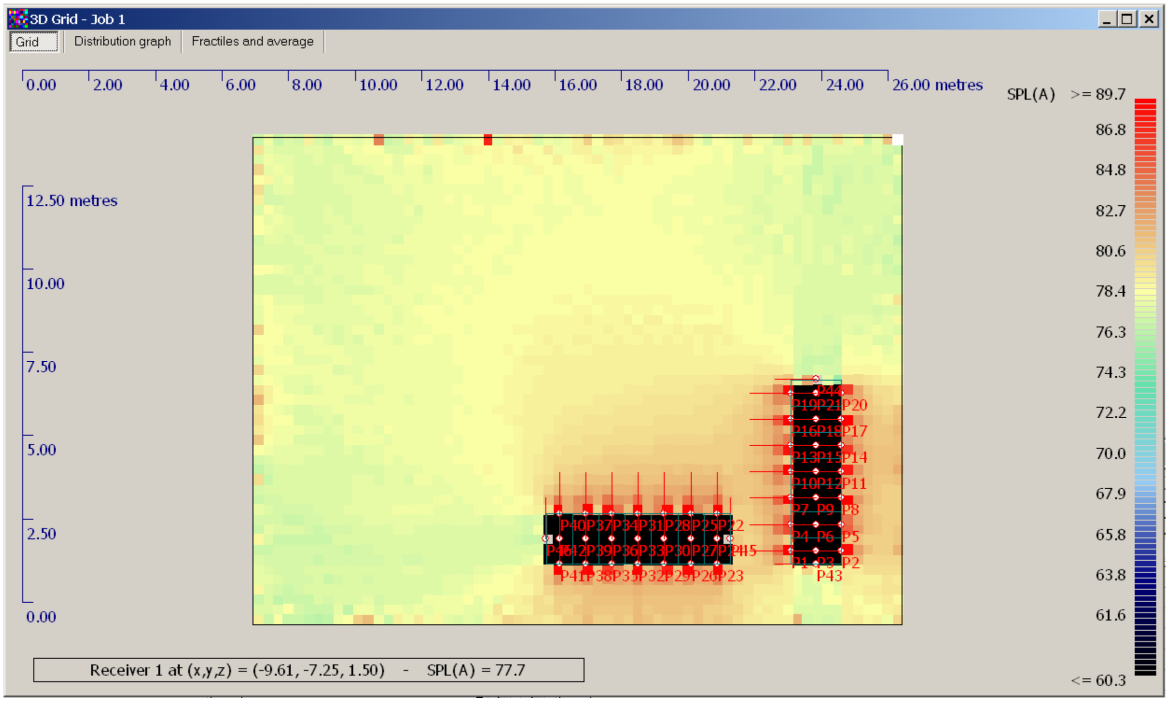
Figure 9 – Sound Pressure Levels (A-weighted, dB re:20µPa) of Configuration A with 0.01 absorption coefficients (highly reflective)



Receiver 1 at (x,y,z) = (-9.61, -7.25, 1.50) - SPL(A) = 64.4

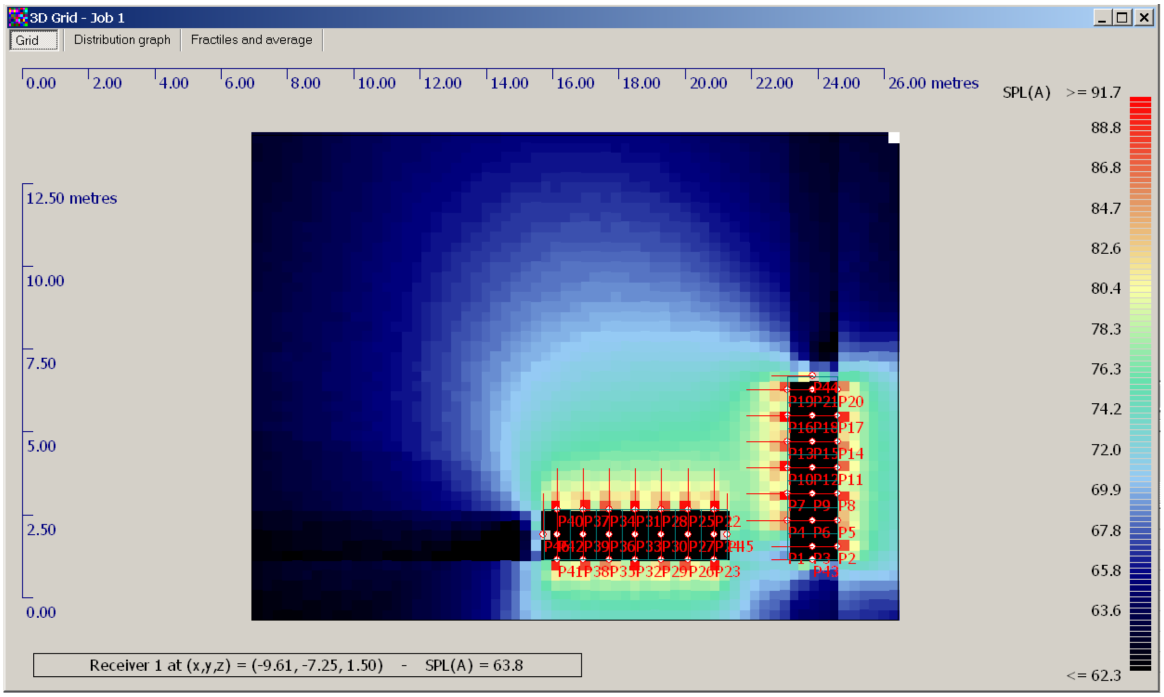
Figure 10 – Sound Pressure Levels (A-weighted, dB re:20µPa) of Configuration A with 0.99 absorption coefficients (highly absorptive)

Lastly, Configuration A2 and Configuration A3 were tested using highly reflective and highly absorptive room surfaces in addition to rearranging the positions of the 14 servers. The following are the sound pressure level contours for those simulations.



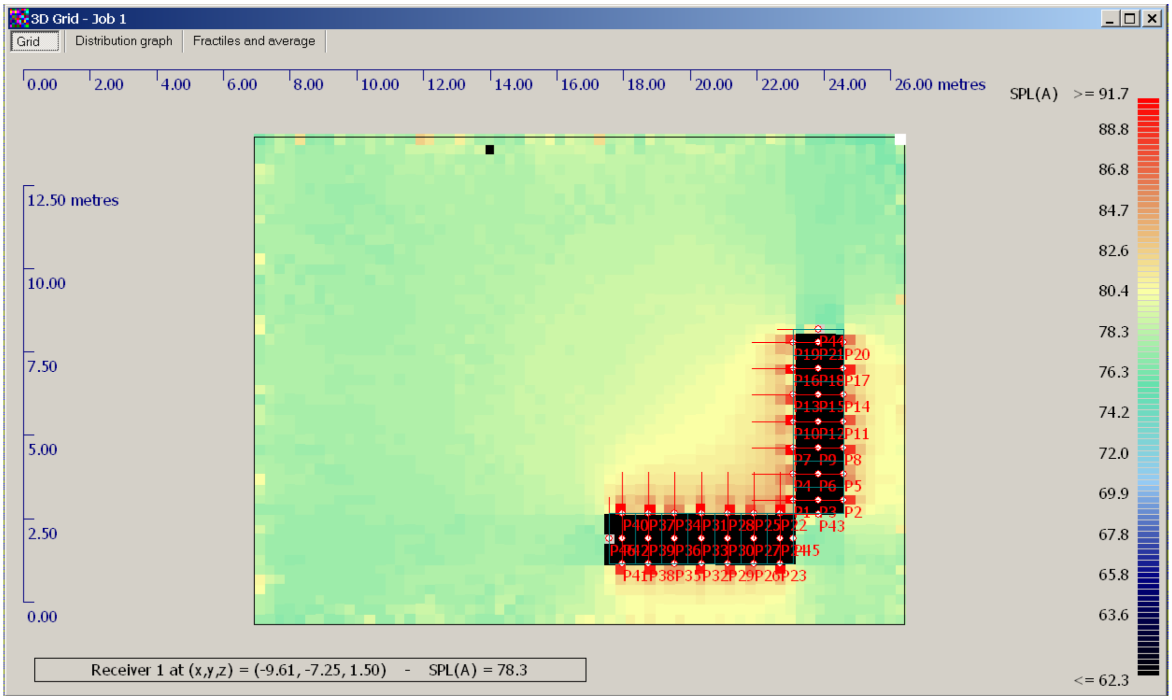
Receiver 1 at (x,y,z) = (-9.61, -7.25, 1.50) - SPL(A) = 77.7

Figure 11 – Sound Pressure Levels (A-weighted, dB re:20µPa) of Configuration A2 with 0.01 absorption coefficients (highly reflective)



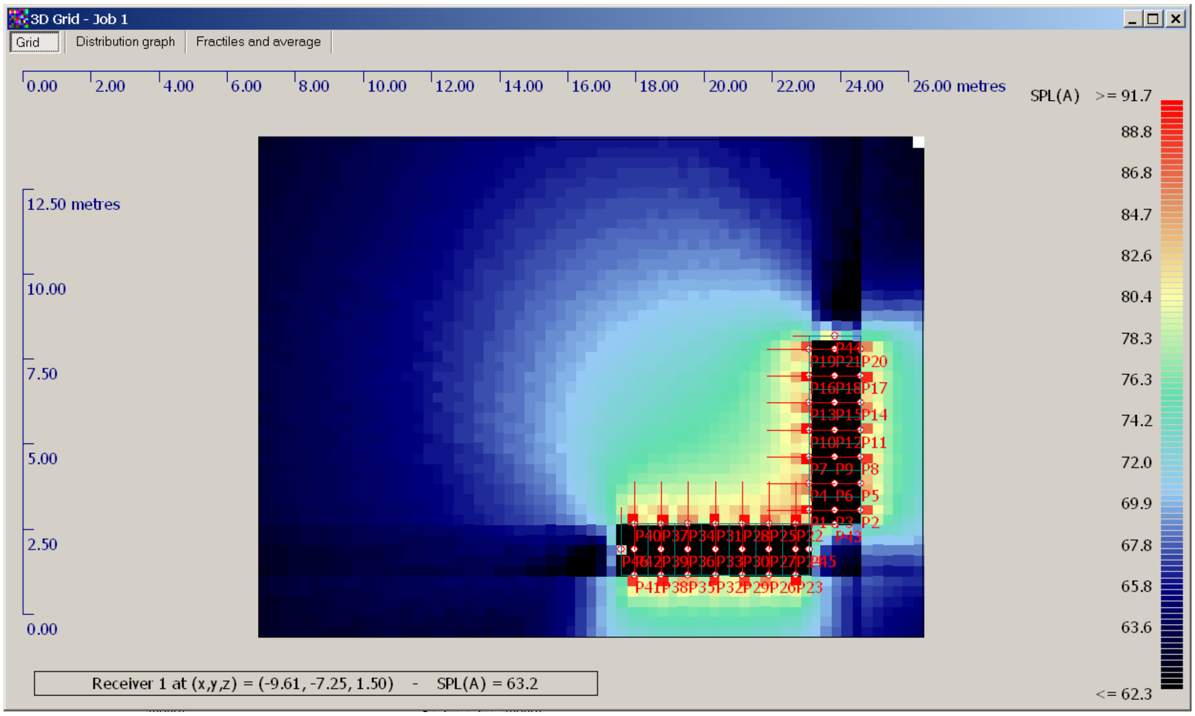
Receiver 1 at (x,y,z) = (-9.61, -7.25, 1.50) - SPL(A) = 63.8

Figure 12 - Sound Pressure Levels (A-weighted, dB re:20µPa) of Configuration A3 with 0.99 absorption coefficients (highly absorptive)



Receiver 1 at (x,y,z) = (-9.61, -7.25, 1.50) - SPL(A) = 78.3

Figure 13 – Sound Pressure Levels (A-weighted, dB re:20μPa) of Configuration A3 with 0.01 absorption coefficients (highly reflective)



Receiver 1 at (x,y,z) = (-9.61, -7.25, 1.50) - SPL(A) = 63.2

Figure 14 - Sound Pressure Levels (A-weighted, dB re:20μPa) of Configuration A3 with 0.99 absorption coefficients (highly absorptive)

Configurations A, C, and E, utilizing typical room absorption characteristics, exhibit a relatively even distribution of sound pressure levels throughout the perimeter of the room (Figures 6, 7, and 8). Sound levels around the servers and particularly in the aisles between the rows are higher than these perimeter values and meet or approach the 85 dBA (re: 20 µPa) Action Level. Sound pressure levels in Configuration A with highly reflective surfaces included approximately 3 dB more of noise around the perimeter of the room with similar levels in the aisle compared to the simulation with typical room absorption characteristics (Figure 9). Configurations A2 and A3 with highly absorptive surfaces create a quiet zone in the opposite corners of the room with significantly lower sound pressure levels while the levels near the servers remain high (Figures 12 and 14).

Discussion

As more servers were added in Configurations A and C, it became apparent that the sound pressure levels throughout the room and in close proximity to the server tend to plateau (Figures 6, 7, and 8). In particular, levels in the aisle way approach but never exceed 90 dBA (re: 20µPa) even as the absorption characteristics of Configuration A were varied. This trend follows the expected sound level distribution within an enclosed space, wherein the sound levels plateau in the reverberant field, but there is minimal change in sound level in the near field of the source as the amount of absorption is varied (Figure 15).

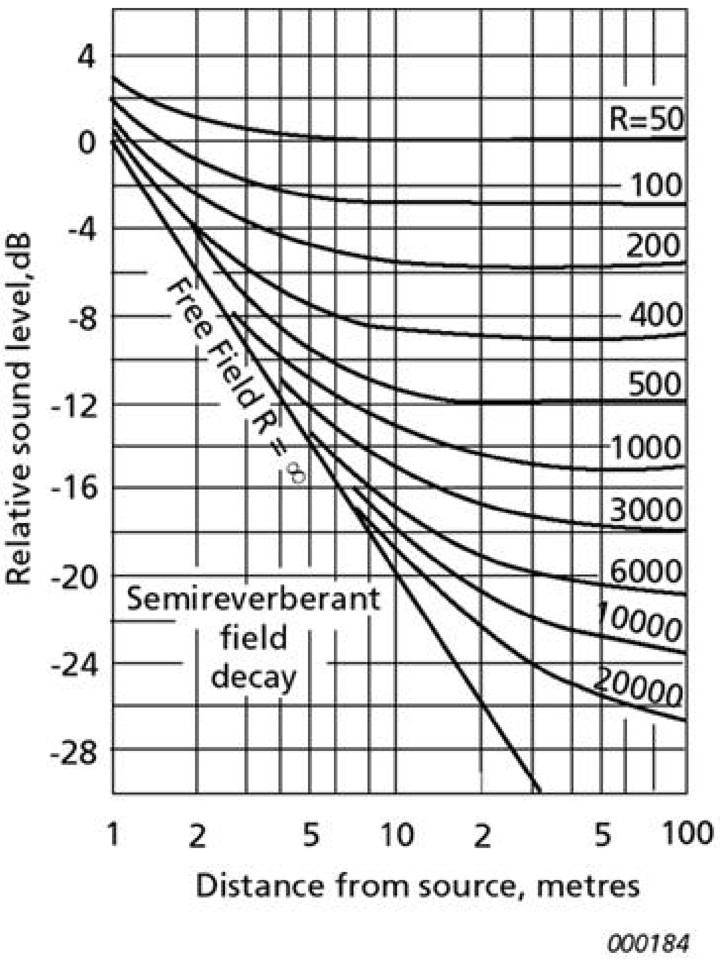


Figure 15– Sound Field within an Enclosed Space with Varying Absorption

This plot illustrates the point that workers spending time operating and adjusting the servers and their components while in close proximity (in the near-field of the noise sources), will experience high levels of noise despite the amount of room absorption. Consequently, it is more likely these employees will be subjected to levels near or above the OSHA action level.

When the servers were placed a greater distance away from a potential position of an employee's desk, a quiet zone was created (Figures 16 and 18). However, noise levels close to the servers were not significantly lower. This solution then becomes impractical for employees as they will still be exposed to dangerously highly noise levels in the course of a work day.

Recommendations

In order to achieve lower levels of noise exposure to workers in this type of environment, the source of the noise (servers) must be made quieter. In particular, the cooling systems used to maintain appropriate temperatures for the server components tend to be the most significant source of noise. Designing systems that use quieter components but still address thermal issues would be the best way to reduce the noise dosage sustained by employees. Furthermore, a closed duct cooling system that relied on air being circulated directly from the Air Handling Unit into and from the rack servers, bypassing the data center room might yield a decrease in the room-born noise emitted by the HVAC system. With typical designs, circulating air through the room using fans and diffusers results in turbulent flow and an increase in noise.

An alternate approach is to implement a zone method and remove employee's desks from server rooms. When employees are in these rooms and are working on the servers, hearing protection devices such as earplugs can be a cost effective way of protecting the well-being and improving the productivity of employees during those exposure periods.

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