

Noise within a Data Center

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Abstract - Data centers with its numerous servers, network switches, routers and air conditioning equipment produce significant noise that influences work and communication of maintenance staff. Noise levels and spectrum within a data center are measured and analyzed. Daily and weekly variations of noise levels are also captured. From measured noise levels and spectrum speech intelligibility measures are calculated and communication distances within a data center are determined. The need for noise protection and methods for noise reduction are considered.

I. INTRODUCTION

Work in a data center exposes staff to some suboptimal working conditions. Noise, temperature and air circulation are three of the biggest environmental issues that data center workers face. Air-condition and equipment cooling fans necessary for the proper operation of IT equipment run continuously and create excessive noise that influence comfort, poses risk to hearing and impairs communication and concentration. With the introduction of smaller hardware, data center is even more densely populated and noise inside is becoming louder. Constant humming of air-conditioners and servers within a data center may create noise sometimes in excess of 80 dBA. Although maximum acceptable 8 hour exposure level in most countries is set at 85 dBA, as 10% of the level that does not show any effect (NOEL - No Observed Effect Level), this level is far above levels prescribed for mentally demanding work and office environment.

II. SOURCES OF DATA CENTER NOISE

Data centers consist of servers, routers, switches, storages, tape systems, UPS and cooling equipment (HVAC – Heat Ventilation Air Condition). Main sources of data center noise are shown in Fig. 1. HVAC with its supply ventilation ducts is a single main source of a data center noise, with noise level typically about 70 dBA. Within IT equipment main contributors to data center noise are cooling fans installed in numerous servers, routers, switches and storages, although some minor noise comes from disks, tape drives, transformers and human

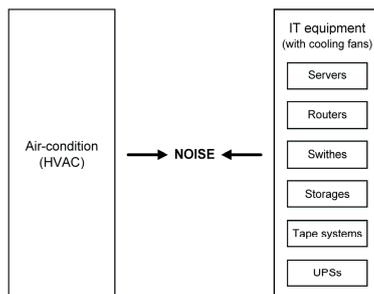


Figure 1. Main sources of data center noise

intervention. Individual servers produce noise levels in a 40-70 dBA range, depending on the brand and size, [1].

The sound power (not SPL) of centrifugal and axial fans (such as used in HVAC ventilation ducts) is given by (1), [2]:

$$L_w = K_w + 10 \log_{10} Q + 20 \log_{10} P + BFI + C_N \quad (1)$$

where

- L_w sound power level
- K_w specific sound power level depending on a type of fan (obtained from manufacturer data)
- Q volume flow rate
- P total pressure (inches of H₂O)
- BFI blade frequency increment, correction for pure tone (obtained from the graphs)
- C_N efficiency correction (out of optimum flow conditions, obtained in tables)

When there are hundreds of servers, with hundreds of cooling fans, noise levels are considerably higher than in the case of one server. Considering them as noise sources that are not coherent, level difference is given by (2):

$$\Delta L = 10 \times \log n \quad (2)$$

where

- ΔL is the level difference
- n is the number of equally loud noise sources

Permissible Exposure Time for various noise levels (according to NIOSH) may be calculated using (3), [3].

$$t = 480 / 2^{(L - 85)/3} \quad (3)$$

where

- t is maximum exposure duration (seconds)
- L is noise exposure level (dBA)
- 3 is exchange rate (dBA), i.e. for noise level increase of 3 dBA, permissible exposure time is cut in half

Permissible exposure time for noise - guidelines for level and duration (time) are shown in Table I, [4]. Noise exposure level/times exceeding those shown in table require use of hearing protection. When considering working conditions for technicians and visitors in a data center, high noise levels influence not only hearing and communication but negatively influence concentration needed for performing complex cognitive tasks. Some kind of protection may be needed, especially for workers working long shifts to increase concentration, comfort and

TABLE I. PERMISSIBLE TIME EXPOSURE

Level, dBA	85	88	90	92	94	95	100	105	110	115
OSHA PEL	16		8			4	2	1	0,5	0,25
NIOSH REL	8	4			1		0,25			

Duration (in hours) of allowable exposure based on OSHA and NIOSH criteria. PEL = Permissible Exposure Limit; REL = Recommended Exposure Limit

prevent undesirable extra-aural effects (influence on the autonomous system), [5]. When noise levels exceed 85 dBA, hearing conservation programs are required. This includes baseline audiometric testing, noise level monitoring or dosimetry, noise hazard signage, education and training, [6]. Once levels exceed 87 dBA (in Europe) or 90 dBA (in the US), further measures are required like use of hearing protection, rotation of employees, or engineering controls must be taken, [6].

III. SPEECH COMMUNICATION UNDER NOISY CONDITIONS

During various installation and maintenance works communication between staff is of utter importance. Normal conversation tends to occupy 60-70 dBA range. Speech communication in data center is degraded by the masking effect of the background noise and changes in vocal effort are necessary for various background noise levels, [7], as shown in Fig. 2, [8], and Table II.

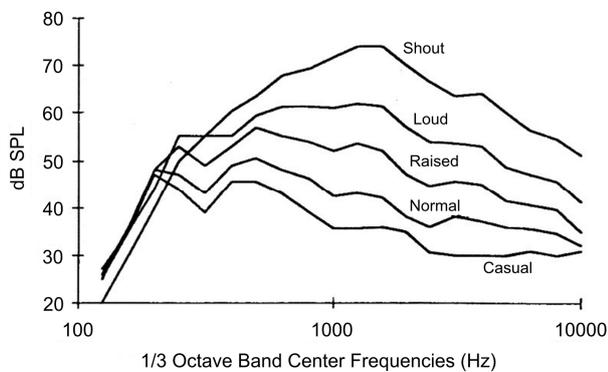


Figure 2. Long-term spectrum of speech under various vocal efforts (adopted from [8])

TABLE II. SPEECH LEVELS AT VARIOUS VOCAL EFFORTS

Voice	Average level dB/dBA
Casual	52.0/42.0
Normal	57.0/47.0 (private speech)
Raised	64.0/57.0
Loud	73.0/62.0
Shout	85.0/72.0

Auditory masking is intrusion of unwanted sounds that interfere with the speech signal. Masking effect of data center noise in spectral domain is illustrated in Fig. 3-5. When the low-frequency noise is louder than the

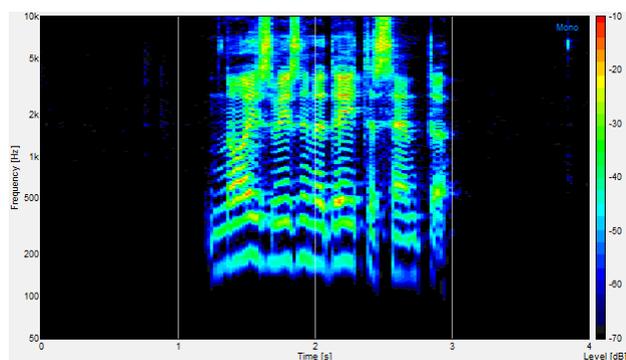


Figure 3. Spectrogram of speech ('Noise within a data center')

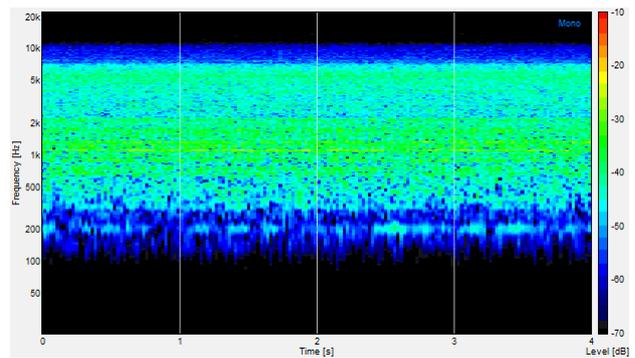


Figure 4. Spectrogram of data center noise

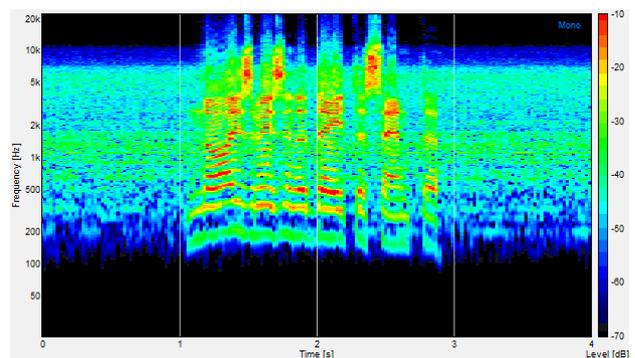


Figure 5. Spectrogram speech plus data center noise combined

speech signal it effectively masks speech. At high sound pressure levels such noise effectively masks both vowels and consonants. High-frequency noise masks only the consonants, and its masking effectiveness decreases as the noise gets louder, [9]. Noise exposure levels in a data center afford less than desired intelligibility (< 95%).

IV. DATA CENTER NOISE MEASUREMENTS

Noise measurements were performed in mid-size corporate data center, of surface area about 170 m². IT equipment installed within a data center is listed in Table III. Temperature inside a data center is kept in 21-22 °C range with separate cabinet cooling systems blowing out air at 18-19 °C.

TABLE III. IT EQUIPMENT WITHIN A DATA CENTER

Type	Number of devices
Server (physical)	120
Storage	5
Tape subsystem	3
Routers/ Switches	15
Cabinet Cooling System	10

A. Measuring Equipment

Noise levels were measured using the CEM DR-805 Sound Meter. A-level weighting was used due to high correlation with people's subjective judgment of the loudness. Noise signals were recorded at 44.1 kHz sampling frequency and 16-bit resolution, using simple Ednet Desktop Microphone with 30 Hz-16 kHz range, HP ProBook 6570b laptop computer with internal audio card and YMEC sound measurement and analyzing software.

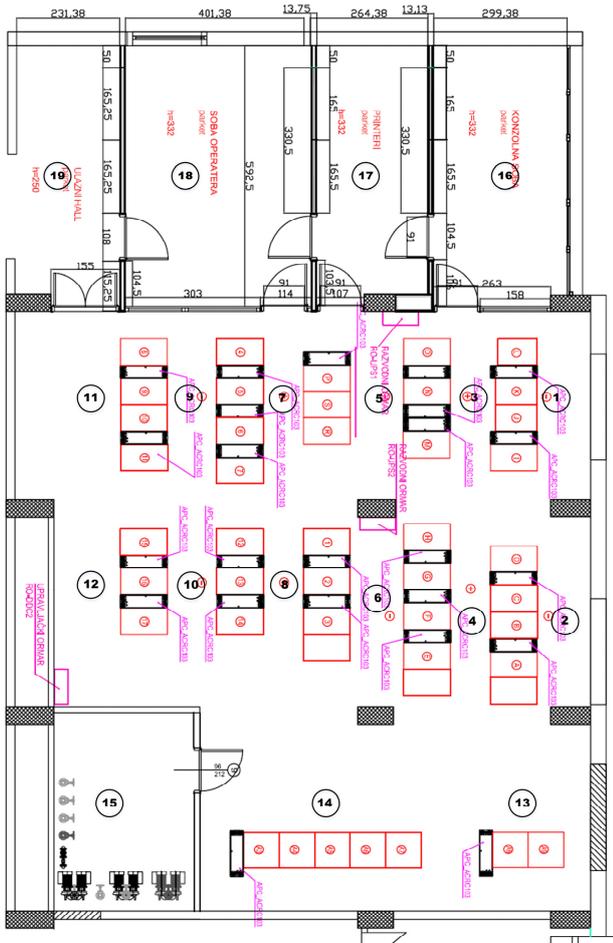


Figure 6. Data center schematic

B. Measured Noise Levels

Noise was measured at 19 different places, 15 in a data center and 4 in accompanying spaces (console room, archive, operators room and at the entrance hall) shown in data center schematic, Fig. 6. All noise measurements were performed at the head level while in standing position. Measurement results are shown in Table IV. Noise level depends if it is measured in a cold or hot aisle. The lowest level in a data center was around 70 dBA and the highest slightly above 80 dBA. Similar values are common in data centers, [10]. Higher levels were measured in hot aisles (where cooling air gets out of servers). The highest level was measured near routers with particularly noisy cooling fans. These levels are below maximum acceptable levels. However repeated exposure to noise levels between 75 and 85 dBA may pose a small risk to some people, [11]. Being so close to the limit and considering excess risk of long term exposure, [4], it may be wise to take no chances and wear some hearing protection. Noise in accompanying spaces was much lower (under 60 dBA). Although this is much less than in data center and staff got used to it, prolonged stay is still quite unpleasant for unaccustomed visitors.

C. Noise Spectrum

Spectrum of data center noise is shown in Fig. 7. Please note harmonic content at frequency range from 150 Hz up to 1.5 kHz that originates from air condition

TABLE IV. NOISE LEVELS AT VARIOUS POSITIONS

Position	Description, contributing sources in aisle	dBA
1	Servers, storage, cabinet cooling system	76,2
2	Servers, storage, cabinet cooling system	76,1
3	Servers, storage, cabinet cooling system	79,2
4	Servers, storage, cabinet cooling system	76,9
5	Servers, storage, cabinet cooling system	78,1
6	Servers, cabinet cooling system	79,1
7	Servers, storage, cabinet cooling system	74,2
8	Servers, cabinet cooling system	75,0
9	Servers, cabinet cooling system	74,7
10	Servers, cabinet cooling system	73,9
11	Servers, cabinet cooling system	70,9
12	Servers, cabinet cooling system	70,9
13	Routers	75,2
14	Routers	80,3
15	Fire central (alarm and dischargers)	70,7
16	Console room	57,8
17	Archive	55,6
18	Operators room	58,5
19	Entrance hall	58,3

and IT equipment cooling fans. These fans operate at discrete frequencies, and certain frequencies like blade passing frequency (BPF), have more power than others. BPF is the product of the fan rotation speed and the number of fan blades, (4), [2]:

$$BPF = \frac{N_R N_B}{60} \quad (4)$$

where BPF is the basic frequency of fan tonal components, N_R is the fan rotation speed (rotations per minute, RPM) and N_B is the number of fan blades. Numerous harmonics are present as multiples of BPF . There is also a considerable noise in a frequency range of 2-7 kHz due to the turbulent air flow produced by the fans. Above 7 kHz noise rapidly diminishes.

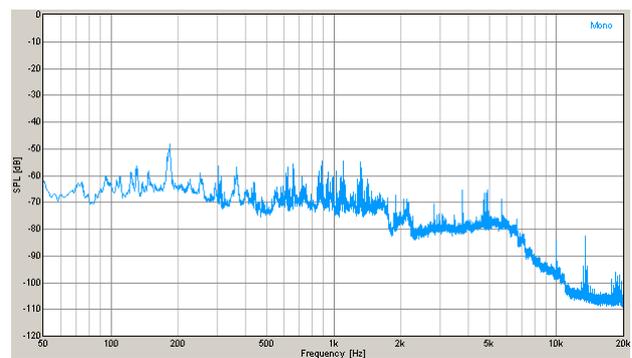


Figure 7. Spectrum of data center noise

D. Daily and Weekly Variations

Data centers have its temperature fluctuations that may indirectly (due to different cooling requirements) influence noise levels. This includes:

- daily variation caused by daily swings in the IT load and outdoor temperature
- day-to-day variation caused by the weather
- IT load reduction on weekends

Daily noise variations measured at position 3 in data center schematic from Fig. 6, are shown in Fig. 8.

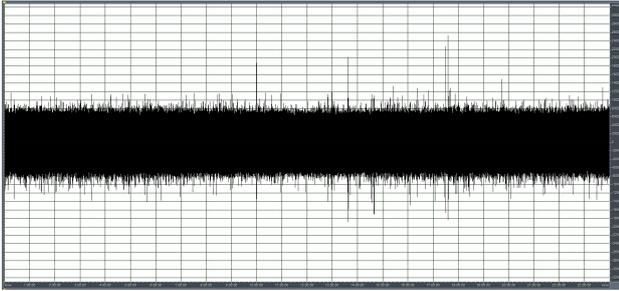


Figure 8. Daily noise variations (linear amplitude scale, working day)

Noise level is quite constant with occasional spikes due to human influence (opening data center doors, opening server cabinets, loud communication etc.). Noise levels averaged in four hour periods are shown in Table V. Summary of daily variations, but averaged over 5s period are given in Table VI. Weekly noise variations of daily averages are given in Table VII.

TABLE V. DAILY NOISE VARIATIONS

Noise level (4 hour average) dBA	0-4	4-8	8-12	12-16	16-20	20-24
	79,4	79,4	79,3	79,3	79,4	79,4

TABLE VI. DAILY NOISE VARIATIONS – SUMMARY

Noise level (5s average) dBA	min	max	aver
	78.5	88.3	79.4

TABLE VII. WEEKLY NOISE VARIATIONS – SUMMARY

Noise (daily average) dBA	Sun	Mon	Thu	Wen	Thu	Fri	Sat
	79,3	79,3	79,4	79,5	79,4	79,4	79,4

Data center where the measurements have taken place is working with low utilization of computing resources and main contributor to temperature changes is the weather alone. As can be seen from our particular case, noise variation during a period of one day and week are negligible. In some data centers temperature fluctuations may be up to 9 °C depending on the time of day, season and the current weather. Much lower temperature excursions (just few degrees) are common in most data centers.

V. MEASURED NOISE LEVELS, SPEECH INTELLIGIBILITY AND COMMUNICATION DISTANCE

Several noise metrics have evolved for assessing the influence of noise on speech, [12].

A. Speech Interference Level (SIL)

Speech Interference Level is defined as the arithmetic average of the sound pressure levels at 500, 1000, 2000 and 4000 Hz octave bands, (5), [12, 13].

$$SIL = \frac{L_{p500} + L_{p1000} + L_{p2000} + L_{p4000}}{4} \quad (5)$$

A-weighted sound level L_{pa} correlate well with SIL for most sounds in aviation, [2]. Acceptable results of SIL values maybe derived from A-weighted noise levels by using the following approximate expression, (6), [13]:

$$SIL = L_{pA} - 10 \quad (6)$$

For data center noise spectral content shown in Fig. 7 and put into (5), more appropriate expression would be (7):

$$SIL = L_{pA} - 12,5 \quad (7)$$

B. Articulation Index (AI)

Articulation Index (AI) is the value, between 0 and 1.0, which describes the masking of speech by background noise. An AI of 1 means that all speech can be understood, and 0 that no speech can be understood. An AI < 0,05 means very poor speech intelligibility, and an AI > 0.80 good speech intelligibility. AI is found by evaluating the signal to noise ratio in specific frequency bands, [12], according to (8), [14].

$$AI = \frac{\sum_{i=1}^n I_i (SNR_i + 12)}{30} \quad (8)$$

where

AI is the Articulation Index

I_i is the frequency importance function for band i

SNR is the Signal-to-Noise Ratio for band i

AI can be calculated from the 1/3 octave band levels between 200 Hz and 6300 Hz center frequencies, using the AI calculator, shown in Fig. 9, [15].

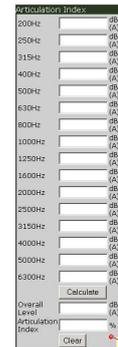


Figure 9. AI Calculator

C. Speech Intelligibility Index (SII)

The Speech Intelligibility Index (SII), [12, 16, 17], is a standardized objective measure which is correlated with the intelligibility of speech under a variety of adverse listening conditions. SII is a function of the long-term average spectrum of the speech and noise signals and is based on the Articulation Index. SII and the AI are not the same thing, but are quite similar. The SII, like the AI, is a quantification of the proportion of speech information that is both audible and usable for a listener. The SII is computed as a product of the frequency band importance function I_i , and the band audibility function A_i , (9).

$$SII = \sum_{i=1}^n I_i A_i \quad (9)$$

The value of the SII varies from 0 (completely unintelligible) to 1 (perfect intelligibility). SSI can be determined using the SII Calculator, Fig. 10, [17].

Speech intelligibility in a data center is determined according to mentioned intelligibility measures. Values for SIL were determined using (5) and scaling the noise values. In a similar way values for AI and SII were determined using AI and SII calculator (for SII calculator

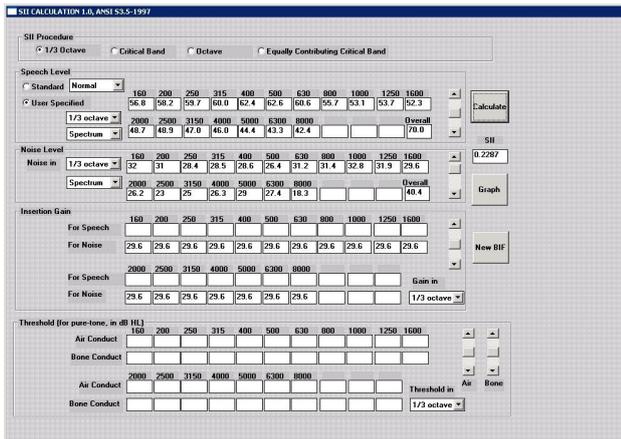


Figure 10. SII Calculator

user specified male speech spectrum normalized to 70 dB SPL was supplied). Speech intelligibility values for various noise levels are listed in Table VIII. At levels within a data center, staff have to talk loudly to be heard.

D. Communication Distance

The distance between the talker and listener (i.e. communication distance) is important when the conversation takes place. Speech levels are reduced typically by 6 dB for each distance doubling between the talker and listener. Communication distances for various values of SIL are shown in Fig. 11, [18], and for various noise levels encountered in a data center in Table VIII.

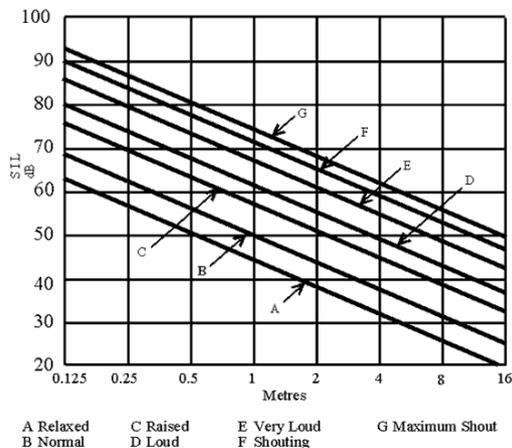


Figure 11. Communication distance for various values of SIL (adopted from [18])

TABLE VIII NOISE LEVELS, SPEECH INTELLIGIBILITY MEASURES AND COMMUNICATION DISTANCES

Noise level, dBA	Speech intelligibility ¹			Communication distance (m)	
	SIL	AI	SII	normal speech	loud speech
55 ²	42,5	0,82	0,66	2,6	9,5
60 ²	47,5	0,66	0,53	1,2	4,5
70	57,5	0,34	0,23	0,44	1,6
72	59,5	0,28	0,17	0,35	1,2
74	61,5	0,22	0,12	0,29	1,0
76	63,5	0,17	0,08	0,23	0,76
78	65,5	0,11	0,06	0,18	0,66
80	67,5	0,06	0,04	0,14	0,53
82	69,5	0,03	0,03	0,13	0,44
84	71,5	0,01	0,02	0,10	0,34

¹normal speech, ²noise levels at accompanying spaces

VI. POSSIBLE NOISE REDUCTION SOLUTIONS

A. Passive Noise Reduction

Data center with its walls, floors and ceiling surfaces provide little acoustic absorption. Conventional passive acoustic absorption materials are not used because they are highly flammable and may emit particulates that may trigger fire detection sensors, [19]. Materials used in a data center must be properly fire rated and fiber free. They can be mounted on walls and suspended from ceilings preventing reflections, reducing reverberation and preventing noise build up. It is also possible to use sound dampening server cabinets that use acoustic foam.

Passive noise protection headphones may be used for tasks where no communication is needed. Conventional hearing protection or noise protection headphones restrict the workers ability to communicate. If communication among workers is needed, headphones with integrated wireless communication (like Bluetooth) could be used.

B. Active Noise Control

Noise within a data center consists of tonal and broadband components. Tonal components originate from HVAC fans and equipment cooling fans with pronounced discrete spectrum. Broadband component originates from turbulent airflow. Active Noise Control (ANC) is quite successful at eliminating tonal components. Eliminating these low to mid frequency components would greatly reduce the amount of noise present in the data center.

ANC is generally not suitable for noise attenuation in large spaces, but is mostly restricted to generating local zones of silence. ANC over an extended region is not possible in the data center room in general, [20]. This is due to the random nature of the noise and the high modal density of the room itself. If trying to suppress noise within a large space better approach is to attenuate noise at the source itself, like at ends of ventilation ducts.

ANC can be successfully applied for silencing HVAC ventilation ducts, [21, 22], Fig. 12. Ventilation ducts contain low to mid frequency tonal and broadband noise. ANC systems for silencing ventilation ducts have been developed decades ago, but with reduced cost of signal processing hardware are becoming feasible for common use. In laboratory, ANC can achieve 15-25 dB additional noise reduction at frequency range of 50-350 Hz, [21], and values of 10-15 dB are reported in a real world, [22]. Specially designed add-on unit can be installed at the end of a pipe emitting or sucking air and generating noise.

ANC within servers, integrated with cooling fans, is something to be common in a future. Such system uses a magnetic field to generate minute vibrations in fan blades. A microphone samples the noise and then tunes the fan blade vibration to cancel it out, [23].

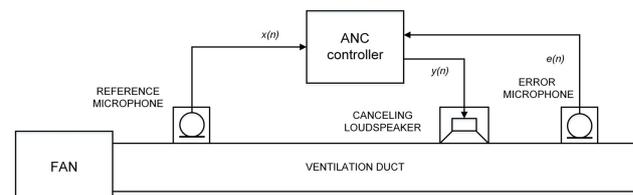


Figure 12. ANC in a ventilation duct

ANC headphones, [24], can provide greater deal of protection, however most of ANC headphone designs are optimized for aircraft use. Although ANC headphones are successful at reducing noise, they also reduce the ability to hear speech and remain aware of surroundings. Some communication headphones combine speech enhancement with noise suppression technology that elevates speech and suppresses dangerous background noise so workers can hear speech and stay protected in high noise environments, [25]. Sometimes even situational awareness with speech and noise direction recognition is preserved.

C. Lowering Cooling Requirements

HVAC is the main source of noise in a data center. According to [6], 20% increase in cooling air speed equates to a 4 dB increase in noise level. By reducing HVAC activity it is possible to reduce noise.

Lower cooling requirements on HVAC can be achieved by implementing higher degree of virtualization and hence achieving higher CPU usage and the lower number of necessary physical servers. Overall power consumption, cooling requirements and noise levels go down. However efficiency of power and cooling infrastructure gets worse because of underloading, [26].

Another approach is raising target temperature within a data center, [27]. The higher the target temperature in a data center, the lower is the cooling requirement. HVAC unit should not necessary run at full capacity at all times. Increasing target temperature for just few degrees during maintenance activities would lead to a quieter work environment for employees. Recommendations for air temperatures in data centers (Class 1 requirements) put them in a range 18-27 °C (allowable 15-32 °C), [28]. As an approximation it may be expected that 2°C increase in data center temperatures would cause noise decrease of 3-5 dB, [6]. Server fans will, however, try to compensate for diminished HVAC operation using the server built-in temperature-based fan speed control, adding some noise.

VII. CONCLUSION

Measured noise levels within a data center were in 70-80 dBA range (as in other data centers). These levels are below maximal acceptable eight hour exposure limit but are close enough and it may be wise to use some kind of hearing protection like noise protection headphones. Prolonged exposure to such noise levels could produce extra-aural health effects. High noise levels interfere with performing cognitive tasks, influence autonomous system and after the long-term exposure may cause behavior modifications. Noise in a data center significantly interferes with speech intelligibility (as reflected in speech intelligibility measures), making communication among personnel difficult (raising voice and reducing communication distance). Lightweight ANC headphones with build in wireless interphones would be beneficial. Staff should perform as much as possible tasks remotely from the office, using iLO console or RD connections. Passive noise reduction with certified fire resistant materials may be applied to data center surfaces. ANC is suitable for HVAC ventilation ducts. During extensive maintenance activities temperature throttling can be used.

REFERENCES

- [1] TechMikeNY, Server Guide, Internet: <https://techmikeny.com/server-guide/> [February 29, 2016]
- [2] Fan Noise Prediction, Internet: http://www.mne.psu.edu/lamancusa/me458/11_fan.pdf [February 29, 2016]
- [3] Noise Exposure - Permissible Level and Duration, Internet: http://www.engineeringtoolbox.com/noise-exposure-level-duration-d_717.html [February 29, 2016]
- [4] Patricia T. Johnson, Noise Exposure: Explanation of OSHA and NIOSH Safe-Exposure Limits and the Importance of Noise Dosimetry, ER078114 –B, Etymotic Research
- [5] Sharp L. F., Swiney J. F., Dansby M. R., Hyatt S. C. & Schimmel D. E.: Behavioral and physiological correlates of varying noise environments, EPA-600/1-77-038, EPA, June 1977
- [6] ASHRAE Publication, 2008 ASHRAE Environmental Guidelines for Datacom Equipment, ASHRAE, 2008
- [7] Pearsons K., Bennett Ricarda L. & Fidell S.: Speech levels in various noise environments, EPA-600/1-77-025, EPA, May 1997
- [8] P. H. Stypulkowski, "Circuitry options, signal processing under altered signal conditions", in Tobin, H (ed.): Practical Hearing Aid Selection and Fitting, DIANE Publishing, 1997
- [9] R. Jones, Factors That Affect Intelligibility in Sound Systems, Meyer Sound, Internet: <http://www.meyersound.com/support/papers/speech/section2.htm> [February 29, 2016]
- [10] D. Alger, DC Deconstructed | Sounds of a Data Center, Cisco, Internet: <https://www.youtube.com/watch?v=EQTgpE35zSM&nohtml5> [April 6 2015]
- [11] National Standard for Occupational Noise [NOHSC: 1007(2000)], 2nd Ed., Canberra, Australia, July 2000
- [12] Newman J. S. & Beattie K. R., Aviation Noise Effects, Report No. FAA-EE-85-2, US DoT FAA, March 1985
- [13] D. Miljković, J. Ivošević and T. Bucak, "Psycho-acoustical ergonomics in a light aircraft interior", Proc. of Ergonomics 2013, pp. 111-116, 12-15 June 2013, Zadar, Croatia
- [14] H. Bächler and A. Vonlanthen, "Signal processing tools to support your manner of communication", Phonak Focus 17, 1994
- [15] Articulation Index, Internet: <http://www.diracdelta.co.uk/science/source/a/r/articulation%20index/source.html> [February 29, 2016]
- [16] American National Standard ANSI S3.5-1997, Methods for Calculation of the Speech Intelligibility Index
- [17] SII CALCULATION 1.0, A Software for ANSI S3.5-1997
- [18] Transportation Safety Board of Canada (TSB), Railway Investigation Report R98V0148, [February 29, 2016]
- [19] Y. Joshi and P. Kumar (ed.), Energy Efficient Thermal Management of Data Centers, Springer, 2012
- [20] J. Daily, J. Esplin, Z. Collins and M. Shaw, Acoustical Analysis of Active Control in the Server Room of a C7 Data Centers Colocation Facility Feasibility Report, Brigham Young Univ., June 21, 2010
- [21] M. Larsson, Active Noise Control in Ventilation Systems, Blekinge Institute of Technology Licentiate Dissertation Series No 2008:12, Karlskrona, Sweden, 2008
- [22] L. J. Gelin, "Active noise control: a tutorial for HVAC designers", ASHRAE Journal, August 1997
- [23] G. Gasior, Noise-canceling Noctua CPU Cooler Coming in 2014, The TechReport, Internet: <http://techreport.com/news/24947/noise-canceling-noctua-cpu-cooler-coming-in-2014> [February 29, 2016]
- [24] C. Moy, Active Noise Reduction Headphone System, Internet: <http://cero-ruido.blogspot.com/2014/11/active-noise-reduction-headphone-systems.html> [February 29, 2016]
- [25] Sensear, Data Center Industry Case Study, 2014
- [26] Suzanne Niles, "Virtualization: optimized power and cooling to maximize benefits", White Paper #118, Schneider Electric, 2011
- [27] To Lower the Noise Levels in Data Centers, Raise the Temperature, Internet: <http://www.itwatchdogs.com/environmental-monitoring-news/data-center-to-lower-the-noise-levels-in-data-centers-raise-the-temperature-617409> [February 29, 2016]
- [28] 2011 Thermal Guidelines for Data Processing Environments - Expanded Data Center Classes and Usage Guidance, ASHRAE TC 9.9, ASHRAE, 2011