Classroom and Office Noise Reduction in an Educational Institute – A case study

Project Submitted for

ME-564 (Noise and Vibration Control)

Semester 101

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Introduction

Saudi Arabia is currently in the midst of the largest campaign of university and higher education construction and renovation in its history. With the increased emphasis on education, we must repeat old mistakes: the building of classrooms with inferior acoustics, which can have far-reaching implications for learning [1].

Excessive noise and reverberation interfere with speech intelligibility, resulting in reduced nderstanding and therefore reduced learning. In many classrooms in the United States, the speech intelligibility rating is 75 percent or less. That means that, in speech intelligibility tests, listeners with normal hearing can understand only 75 percent of the words read from a list. In 1998, an incredible $7.9 billion was spent on school buildings in USA [2] .

Over the years the teaching environment has changed; class sizes are larger, more demands have been placed upon resources and technology has become an integral part of the classroom. As such the classroom is not the simple environment to teach in as it once was, with computer equipment continuously humming and more students, it means that there is naturally more ambient background noise [3].

In the UK and USA studies have shown that a large number of classrooms have ambient noise levels – when empty – above the recommended levels set by The World Health Organisation, The American Speech-Language Association and the Department for Education and Skills (DfES) [3].

American Speech-Language-Hearing Association (ASHA) has provided several guidelines for classroom acoustics [4]- [5].

ANSI Standard S12.60 for Classroom Acoustics addresses the issues of both reverberation time and background noise and their effect on speech intelligibility by placing maximum permissible levels on each.

Under the new standard, the maximum reverberation time in an unoccupied, furnished classroom with a volume under 10,000 cubic feet is 0.6 seconds, and 0.7 seconds for a classroom between 10,000 and 20,000 cubic feet. The maximum level of background noise allowed in the same classroom is 35 decibels (dBA). By comparison, the loudness of a normal face-to-face conversation is about 60 dBA [6].

Some classrooms in KFUPM have insufficient acoustic design, e.g. all the classrooms of Building 24. This study aims to address these issues.

Case Study: Class Room 24/125

The course ME 564 is held in classroom 24/125 each week. The room is fitted with educational aids like white board, black board, computer, projector and screen. It has chairs and a desk and table. The acoustic quality of the teacher is clear and reaches all parts of the classroom with good quality. However, there is a very annoying source of noise, apparently from the computer in the room which keeps the background noise level in the range of 75 dBA near the desk (see Figure 1 below) to less than 60dBA elsewhere in the room. Such background noise level is unacceptable according to the ANSI S12.60 standards, and annoying especially for those near the source, i.e. the presenter and audience in the front rows.

Figure 1 - The Noise Source (Computer Cabinet and Desk)

Upon further inspection, it was found that the noise is originating not from the computer itself, but from three cooling fans installed at the back of the cabinet, shown below.

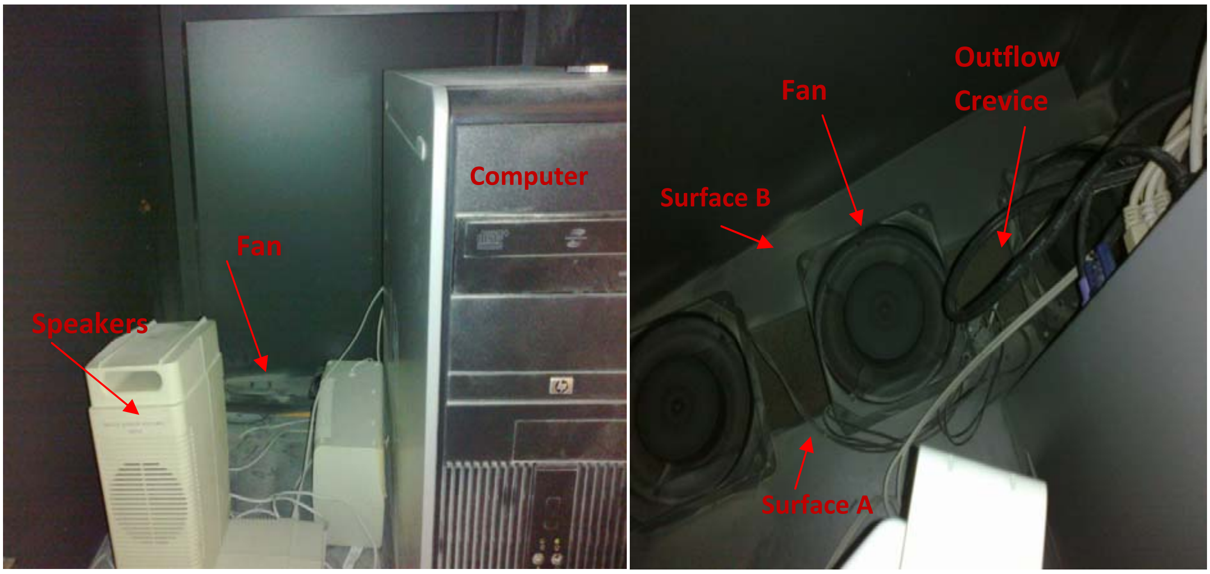

Figure 2 - Inside view of the Computer Cabinet

Even when the computer is shut off considerable amount of noise still lingers in the background. Thus, it was concluded that the main source of noise were the fans, and not the computer itself.

Components of Cooling Fan Noise

Fan noise can be decomposed into the following components:

1. Aerodynamic noise.
2. Bearing noise.
3. Cabinet noise.

In cooling fans for computers, where the aerodynamic noise is low, the predominant noise emitted by the fan is generated in the bearing system. This type of fan usually has either an oil-impregnated sleeve bearing or ball bearings. Both bearing systems create noise that can be very different in both frequency content and amplitude. It is generally accepted in the computer and business machine industries that ball bearing fans are noisier than sleeve bearings fans, as shown in figure 3. Furthermore, ball bearing fans can become noisier by mishandling or long term running [7].

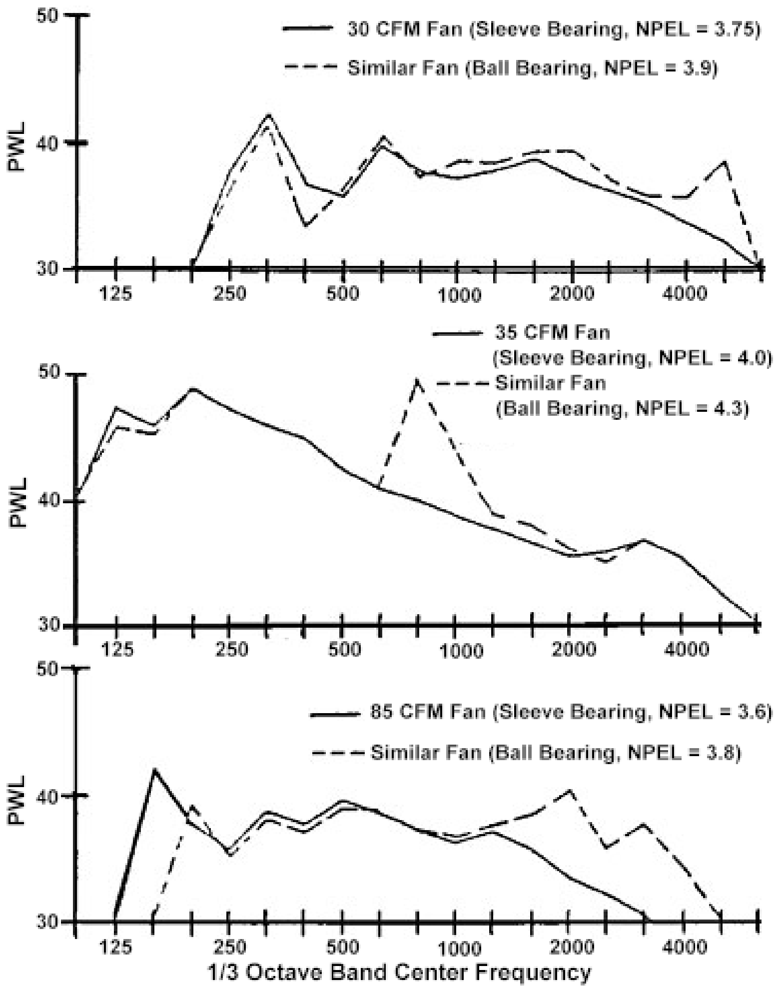

Figure 3 - Ball Bearing versus Sleeve Bearing Noise

For the aerodynamic noise, it is a mixture of vortex shedding, harmonics of blade passing frequencies and broadband turbulent noise. A typical noise spectrum of a 120 mm diameter electronic device cooling fan, with microphone was used at a point 1 m from the upstream side of the fan is shown in figure 4 [8].

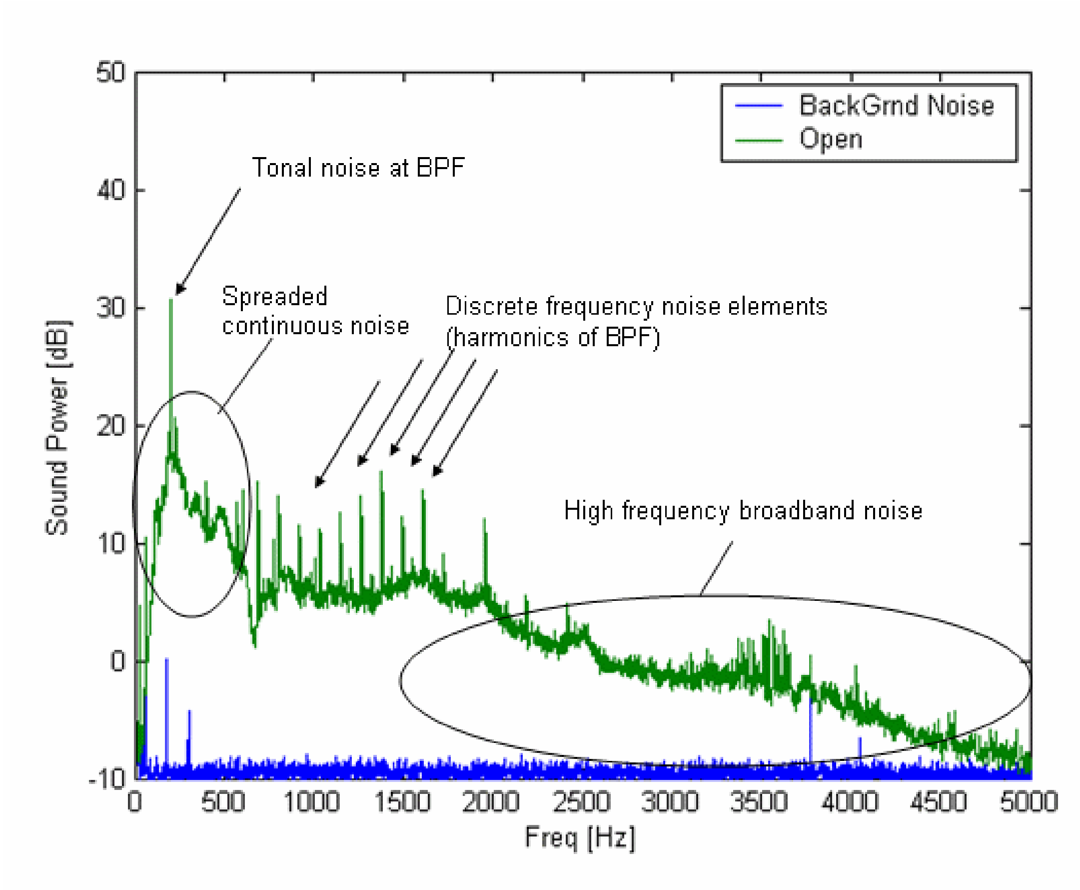

Figure 4 - Typical Noise Spectrum for a 120 mm, 7 blade cooling fan [8].

It is important that the least possible turbulence be created in the airflow. The more turbulence the more noise, especially anything obstructing the air intake [9].

Another dominant source of noise is the vibration of the computer cabinet due to incorrect mounting of the cooling fans. Mounting of the fan can be the greatest source of incremental noise. A fan hard mounted to a resilient surface could introduce vibration. The surface will become a vibrating membrane acting as a speaker membrane to amplify noise [9].

Identifying the components of Cooling Fan:

The first step in identifying the possible solution of the cooling fan noise problem, we need to identify the components of this noise and then target the noisiest ones selectively. To analyze the sound power spectrum, we need to know the specifications of the fans. On dismounting the fans, it was found that they were Sunon DP200A P/N 2123XSL type of AC cooling fans. The specifications provided by the manufacturer (see Appendix) are as follows:

S.No.	Feature	Specification

1	Size	120x120x38mm
2	Frame	Aluminum Alloy
3	Voltage	220-240 V (50/60 Hz)
4	Power Consumption	22 W
5	Speed	2700-3100 rpm
6	Airflow	95-115 cfm
7	Static Pressure	0.33-0.38 in-H_20
8	Noise	44-49 dBA
9	Weight	0.55 kg
10	Number of Blades	0
11	Bearing Type	Sleeve

To be sure about the speed of the fan, we checked it in the Dynamics Lab of Mechanical Engineering Department of KFUPM. It was determined to be 2750 rpm.

Since, BPF = N.k
(1)

Equation 1 (equation 3.1 of [10])gives the blade passing frequency of the fan in terms of fan speed N in revolutions per second and the number of blades.

Using the range of fan speeds specified (2700-3100 rpm), we get

Thus, BPF=f_1=(2700 to 3100)x5/60 = 225-260 Hz

For spectral analysis, we first recorded the noise of the fan using Matlab and did simple spectral analysis of the recorded noise. The Matlab code is given in the appendix. The microphone was placed at the bottom of the crevice where air exist the cabinet (about a centimeter from the floor). The microphone was a standard computer 3.5 mm plug-in microphone (50 Hz-20KHz). The sampling frequency was 2KHz (which filters higher frequencies of background and electronic noise), and the recording was done for 15 seconds in an empty and quiet classroom.

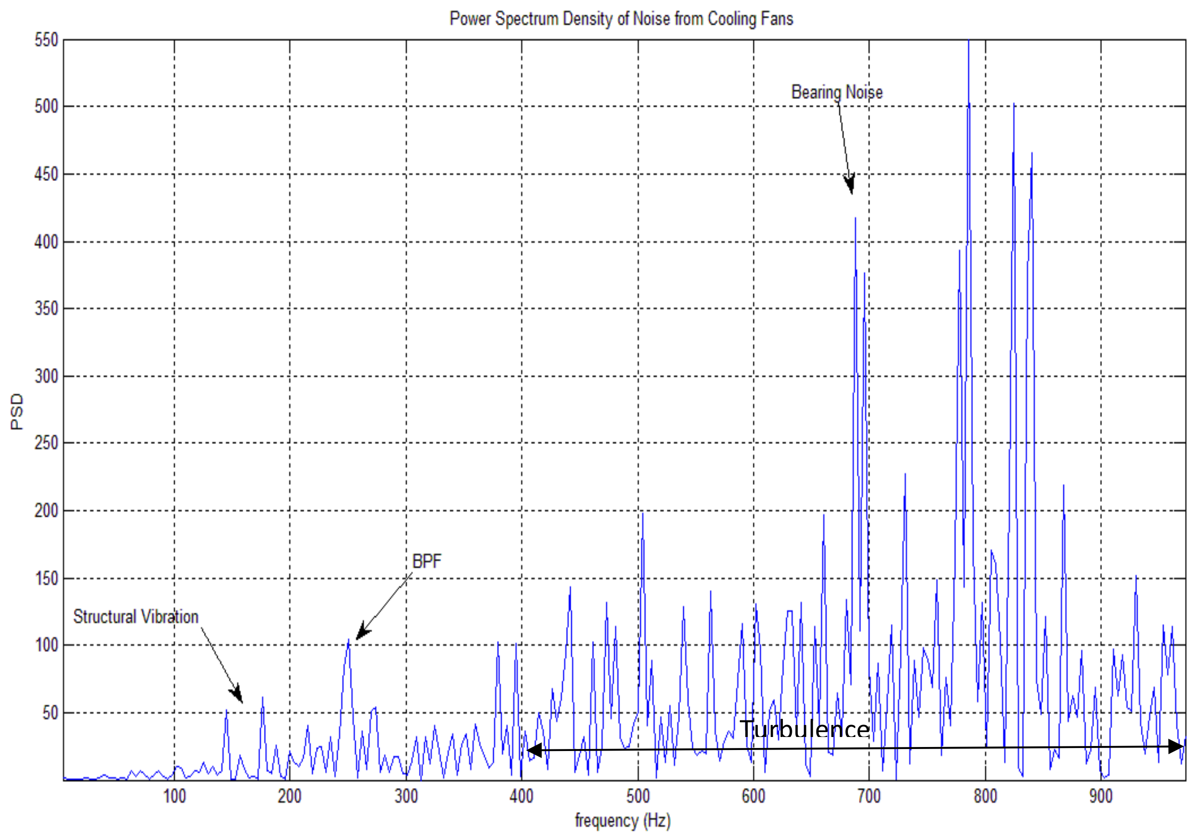

Figure 5 - Power Spectral Density of Noise from Three Cooling Fans in Computer Cabinet

We observe that there is a peak at 250 Hz exactly (corresponding to a speed of 3000 Hz) and its first and second harmonic at 500 and 750 Hz respectively. We can thus safely say that the installed speed of the fans is nearly 3000 Hz.

The vortex shedding frequency of the fan is given by equation 11.6 of [10]:

$$f_a = \frac{\alpha V}{d} \qquad (3)$$

Here, α is Strouhal number (approximately 0.2), V= velocity of air, and d=diameter of cylinder. The outlet diameter of the cylinder is 116 mm, and the motor diameter is 64 mm. Thus, for an flow rate of 115 cfm (0.07 m^3/s), the flow velocity will be 7.3 m/s. Hence, the Aeolian frequency will be 12.6Hz. Since the minimum detectable frequency of the microphone is 50Hz, we cannot be sure of the content at this frequency or its first harmonic.

However there are other peaks at lower frequencies of 145 and 175 Hz. We can identify these lower frequencies as structural vibrations. The higher peaks at 700-850 Hz may be the bearing and turbulent noise.

Now, for axial fans, the average SPL at octave bands 500, 1000, 2000 and 4000 Hz is given by equation 11.3 of [10]:

$$\overline{L_w} = 10\log Q + 10\log P_t + 48 \quad (4)$$

Here, Q = volume flow rate in cfm and P_t=static pressure in inches of water. Since in our case Q is 95-115 cfm and P_t is 0.33-0.38 in, we get:

L_w = 58- 60 dB

This does not agree with the specifications mentioned by the manufacturer, which is perhaps because that correlation is for bigger, faster fans with more blades. For three fans (each radiating sound of 50dB) the total sound level will be:

L_w=50+3+1.8 =54.8 dBA

However, the measured level of noise near the outflow crevice was measured to be around 75 dBA. This means that there is another 20 dBA coming from sources not envisioned by the manufacturer. Common source of noise is the structural vibration caused by incorrect installation of the fans, and the turbulence at fan inlet and outlet. We investigate these sources further in the next section.

Investigating the cause of Noise

Having understood that the main cause of the unaccounted-for noise is structural vibration and turbulence, we proceed to investigate this further. Upon investigating the mounting method of the three fans, the following observations were made:

1. The fans were either not screwed to the wooden base, or in some fans a single screw was used to fix the fan to surface A (see figure 2).
2. The rest of the four corners were glued to the wooden base using a silicone which had now become very hard and brittle (see figure 6).
3. In some cases the unscrewed corners were free and not glued.
4. The vibrations on the structure, for example the surface of the desk were easily sensed by placing a hand on it.
5. A lot of wires to and from the computer were near the inlet of the fans.
6. The outlet of the fans was very near the floor, which then exited into the classroom through a very narrow bottom crevice. This causes much turbulence at the outflow region.

Figure 6 – Fans Mounted in the Cabinet

It is obvious therefore that both turbulence and structural vibrations are sources of the extra noise. We will now recommend solutions for control of noise source.

Control of Noise:

a) First Solution (Active Noise Cancellation)

The first solution we propose is the use of active noise cancellation (ANC) for controlling the noise throughout the classroom. Conventional methods of suppressing acoustic noise using passive sound absorbers generally do not work well at low frequencies. This is because at these low frequencies the acoustic wavelengths become large compared to the thickness of a typical acoustic absorber. A sound wave of frequency I 00 Hz, for example, will have a wavelength of about 3.4m in air under normal conditions. It is also difficult to stop low frequency sound being transmitted from one space to another unless the intervening barrier is very heavy. For these reasons, a number of practically important acoustic noise problems are dominated by low frequency contributions. These problems are sometimes difficult to solve using passive methods since the solutions are expensive in terms of weight and bulk [11].

ANC is based on either feed-forward control, where a coherent reference noise input is sensed before it propagates past the secondary source, or feedback control, where the active noise controller attempts to cancel the noise without the benefit of an “upstream” reference input. Structures for feed-forward ANC are classified into 1) broad-band adaptive feed-forward control with a reference sensor which will be discussed in Section II, and 2) narrow-band adaptive feed-forward control with a reference sensor that is not influenced by the control field (e.g., tachometer) [12].

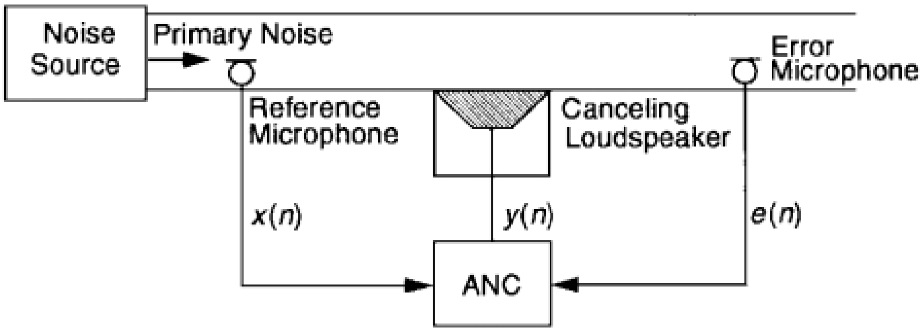

Figure 7- Single Channel Feed-forward Active Noise Control [12]

Active noise cancellation is a technique to cancel the noise by producing an anti-noise. This method of noise control is becoming increasingly popular for a variety of uses. It is sometimes considered a miracle "cure-all" for noise problems which, at the present time, is not the case. For example noise cancellation in 3D spaces, such as living areas, is very difficult to achieve. However it can be more successful locally, e.g. for a passenger sitting in an aircraft or car. There are many institutions and companies around the world working on the technology to increase the circumstances where ANC can be used effectively. This sensitivity to location means that active noise control systems do not work well above 150Hz in large spaces where the ear location is not well defined. One way of controlling this space is to use headsets where the position of the speaker and microphone relative to the ear is well defined and the volume is small. Commercial headsets with active noise cancellation became available for airplane pilots in the early 1990s [12].

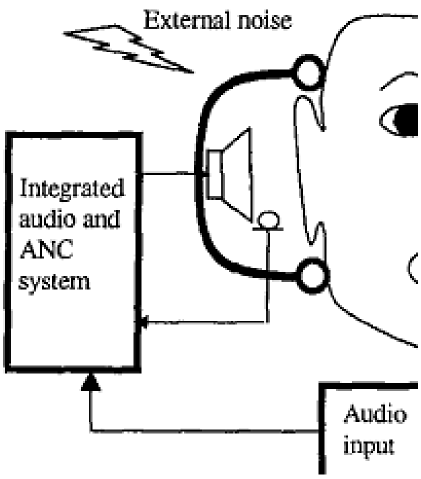

Figure 8 - Active Noise Control Headphone [14]

In ANC headphones, an audio input from audio playback device like walkman or airline in-flight entertainment system is connected to the headphone as the source of signal which needs to be freed from noise. The microphone near or inside the headphone cup can receive both the audio input signal and the outside noise. It acts as an error microphone if it is inside the cup, or acts as a primary microphone if it is outside the cup. The speaker outputs both the anti-noise and reproduces the original signal at the desired amplification (i.e. volume level).

For testing the utility of such a system, we bought a noise-cancellation Sony MDR-NC6 from Radio-Shack in Hyper Panda, Dhahran for SR 255 (nearly 70 USD). The specifications of the headphones are as follows:

S.No.	Feature	Specification
1	Type	Open air, Dynamic
2	Power Handling Capacity	100 mW
3	Impedance	20Ω at 1KHz (power on) 60Ω at 1KHz (power off)
4	Sensitivity	106 dB/mW (power on) 104 dB/mW (power off)
5	Frequency Response	30-1500 Hz (more than 10 dB at 300 Hz)

Figure 9 - Sony NC-6 Active Noise Cancellation Headphones (Left: intact and Right: with cup cover removed)

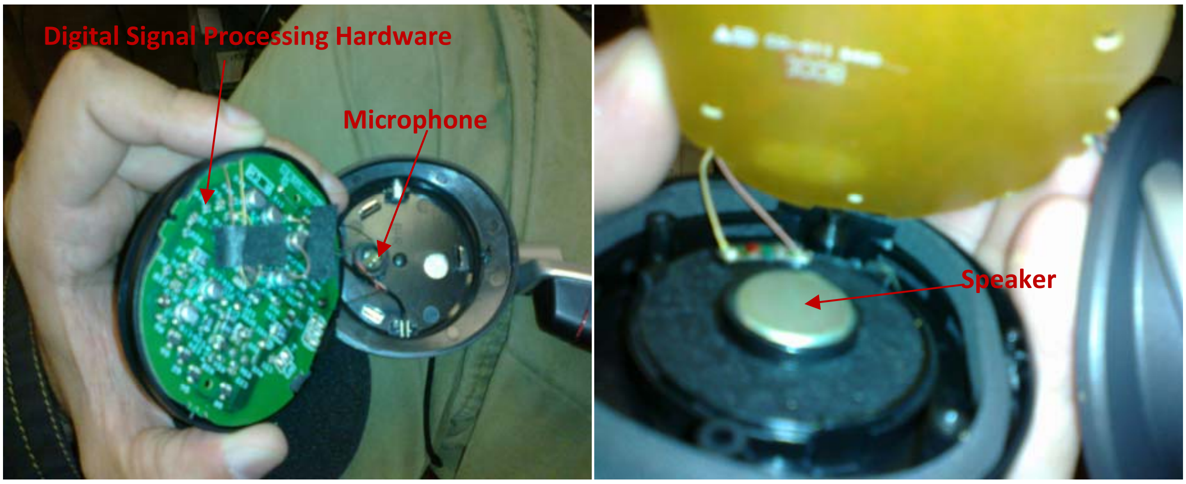

Figure 10 - Stripped Down Sony NC-6 Headphone

On stripping down the headphone, one could locate a microphone, headphone and digital signal processing (DSP) hardware packaged into a small volume. The DSP hardware consisted of an integrated circuit (2076 H129G JRC), and several resistors, capacitors and diodes connected on a printed circuit board (PCB).

During test inside the class, all students were able to experience a remarkable reduction in noise due to the cooling fans. Hence, this proved to be a viable solution, albeit a bit awkward for a class room setting. A more sophisticated setup would be required to implement ANC for the entire room. However, this would cost much more than the price of an ANC headphone.

b) Second Solution (Vibration Isolation)

Since it was determined that structural vibrations were a major source of vibration, one possible solution is to isolate the vibration of fans from the supporting base. There at three major types of vibration isolators: a)metal springs, b) elastomeric mounts, and c) resilient pads [10].

We first chose rubber pads as a base for the four corners of the fan (see figure 11). For this the hardened glue had to be removed first with a saw. The rubber pads were bought from a utility store. These pads are marketed for the purpose of protecting door handles from banking against the wall etc. They did provide some isolation, but this was further improved by adding other materials mentioned below.

Figure 11 - Rubber Pads as Vibration Isolators

In order to provide further isolation, the pads were now mounted on packing material for electronic equipment (see figure 12). This too provided further isolation, but the vibration could still be felt by placing a hand on the desk.

Figure 12 - Fan placed on Packing Foam (center) and blackboard duster (right)

When the foam was placed on a blackboard duster, the vibration was seen to increase more than when it was placed on the packing foam. To alleviate the vibration further, we introduced a third material i.e. a kitchen scrub (like a felt pad). See figure 13.

Figure 13 - Three Layered Isolation

This method, with three layers of isolators provided the most isolation (as felt by hand placed on top of the desk). It reduced the noise from 72 dBA to 64 dBA (see figure below). The sound level meter used was Bruel and Kjaer 2331.

Figure 14 - Sound Power Level, before (left)and after (right) the vibration isolation.

It was obvious that vibration induced by the fans was a major component (about 9 dBA) of the extra noise (20 dBA). Thus, mounting the cooling fans is a major factor of noise generation.

c) Third Solution (Noise Absorbers)

Much noise was observed if the spectrum was analyzed at higher frequencies. However, it was not clear if it was higher frequency noise in the microphone and electronic circuit, or some 'real' acoustic noise. For this purpose, we bought about 150 kitchen scrubs (fibrous, porous material) and installed some of them inside the cabinet (see figure 15). However, only 1 dbA reduction in noise was achieved. It can thus be determined that the noise was part of electronic circuitry of the microphone, and not acoustic in nature.

Figure 15 - Noise Absorbers (left) produced a further 1dBA reduction (right) in noise SPL

d) Third Solution: Selecting Quieter Fans

We should calculate the actual requirement of cooling fan, since it seems that the number and type of fans are incommensurate with the requirement for heat removal. The requirement for airflow requirement for a computer is given by [9]:

$$Q = \frac{3.16W}{\Delta T} \tag{5}$$

Here, Q = volume flow rate in cfm and ΔT= temperature rise and W= heat dissipated by computer in watts. For a HP Compaq dc7800 Business Desktop PC [15], the maximum heat dissipation is 1916 Btu/hr (562 Watts). If we assume that the ambient temperature is 70°F, and the temperature allowable inside the cabinet is 80°F (generally it can be about 90°F). Then, Q = 180 cfm. For a two fan solution, this would mean 90 cfm per fan, or for a three fan solution it would mean 60 cfm per fan.

If we search in the catalog [16]of the fan manufacturer of the current fan (Sunon), we can make the choice for three Sunon DP 203A with a flow rate of 84 cfm, static pressure of 0.21 inch H_2O and speed of 2500 rpm. It has a noise specification of only 38 dBA. If we relax the requirement of temperature to 85°F inside the cabinet, we could use only 2 of these fans, which would mean a noise SPL of 41 dBA (or 43 dBA for three fans). This is much lower than 55 dBA (50+3+2) specified for the existing fans. Even if an additional 10 dBA is added for turbulence, it would still be 20 dBA less than the current level of 75 dBA in the classrooms in building 24.

e) Fourth Solution: Reducing Turbulence

It was observed than the bottom crevice for the outflow crevice (see figure 15), was at 90° to the flow of air from the turbine. This, and the presence of wires near the inflow of fans created much turbulence, and was probably responsible for about 10 dBA more of noise. To avoid this, we suggest that fans should be installed in the vertical position against the walls of the desk, and holes should be cut out for their outflow. This will provide free space for the inflow and outflow of the fan. We also recommend installing the fans with a nacelle inlet, or an aerodynamically shaped nozzle. It is also recommended to make the fan run only when required (such as a temperature threshold) or regulating the fan speed by temperature feedback.

Conclusion

In this project, we successfully applied the material taught in ME 564 (Noise and Vibration Control) at KFUPM during the fall of 2010. We were able to reduce the noise level by 10 dBA by vibration isolation and passive noise control by absorbing material. We also demonstrated the usefulness of ANC headphones in cancelling this type of noise. Moreover, recommendations were also made to make the classroom still quieter by employing quieter fans, mounted correctly at better locations.

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Appendix

Matlab Code to Analyze Spectrum of Noise

a) To get input from microphone

```
Fs = 2000; % Sampling Frequency
y = wavrecord(15*Fs,Fs,1); % Record for 15 seconds
wavwrite(y,Fs,16,'3fan_test'); % write to wav file
```

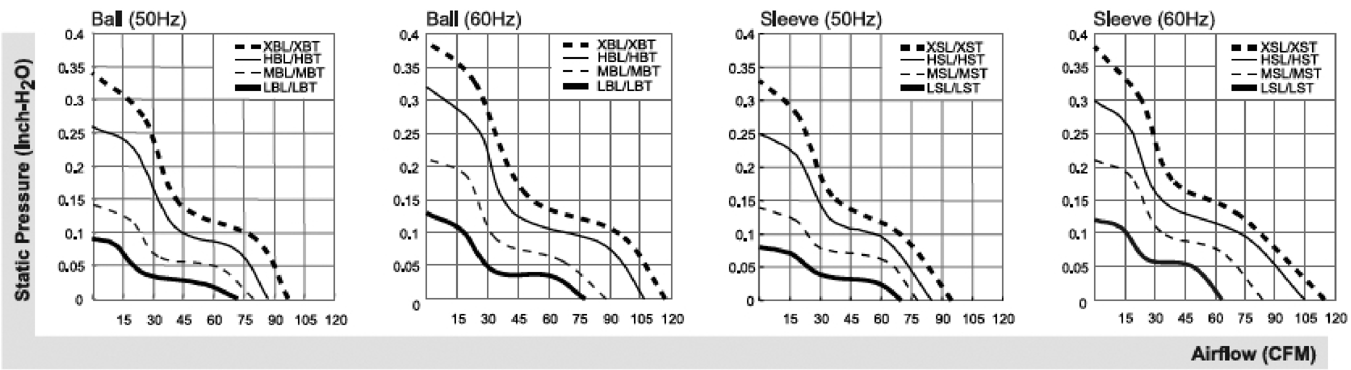
b) Spectral Analysis

```
[y,Fs,bits] = wavread('3fan_test.wav'); %Read wav file
N=512;%Window Length of FFT
Y = fft(y); %Perform FFT
Pyy = Y.* conj(Y) / N; %Power of signal
f = Fs*(1:250-1)/N; %frequency vector
plot(f,Pyy(2:250));grid;xlim([0 Fs/2]);axis tight;
title(Power Spectral Density of Fan Noise')
xlabel('frequency (Hz)');
```

70-117 CFM

Model	P/N	Bearing (● VAPO ○ BALL ⊙ Sleeve)	Rating Voltage (VAC)	Freq. (Hz)	Power Current (AMP)	Power Consumption (WATTS)	Speed (RPM)	Air Flow (CFM)	Static Pressure (Inch-H_2O)	Noise (dBA)	Weight (g)
DP200A	2123XSL.GN	⊙	220-240	50/60	0.14/0.12	22/21	2700/3100	95/115	0.33/0.38	44/49	550
DP200A	2123XST.GN	⊙	220-240	50/60	0.14/0.12	22/21	2700/3100	95/115	0.33/0.38	44/49	550
DP201A	2123HSL.GN	⊙	220-240	50/60	0.125/0.11	20/19	2550/2900	85/105	0.25/0.30	43/48	550
DP201A	2123HST.GN	⊙	220-240	50/60	0.125/0.11	20/19	2550/2900	85/105	0.25/0.30	43/48	550
DP202A	2123MSL.GN	⊙	220-240	50/60	0.09/0.08	16/15	2300/2500	78/84	0.14/0.21	33/38	550
DP202A	2123MST.GN	⊙	220-240	50/60	0.09/0.08	16/15	2300/2500	78/84	0.14/0.21	33/38	550
DP203A	2123LSL.GN	⊙	220-240	50/60	0.06/0.05	11/10	2000/1800	70/63	0.08/0.07	36/32	550
DP203A	2123LST.GN	⊙	220-240	50/60	0.06/0.05	11/10	2000/1800	70/63	0.08/0.07	36/32	550
DP200A	2123XBL.GN	○	220-240	50/60	0.14/0.12	22/21	2850/3150	97/117	0.34/0.39	45/50	550
DP200A	2123XBT.GN	○	220-240	50/60	0.14/0.12	22/21	2850/3150	97/117	0.34/0.39	45/50	550
DP201A	2123HBL.GN	○	220-240	50/60	0.125/0.11	20/19	2750/3050	87/107	0.26/0.32	45/50	550
DP201A	2123HBT.GN	○	220-240	50/60	0.125/0.11	20/19	2750/3050	87/107	0.26/0.32	45/50	550
DP202A	2123MBL.GN	○	220-240	50/60	0.09/0.08	16/15	2400/2600	78/84	0.14/0.21	34/39	550
DP202A	2123MBT.GN	○	220-240	50/60	0.09/0.08	16/15	2400/2600	78/84	0.14/0.21	34/39	550
DP203A	2123LBL.GN	○	220-240	50/60	0.05/0.06	10/10	2300/2150	78/72	0.13/0.09	39/37	550
DP203A	2123LBT.GN	○	220-240	50/60	0.05/0.06	10/10	2300/2150	78/72	0.13/0.09	39/37	550

Frame : Aluminum alloy



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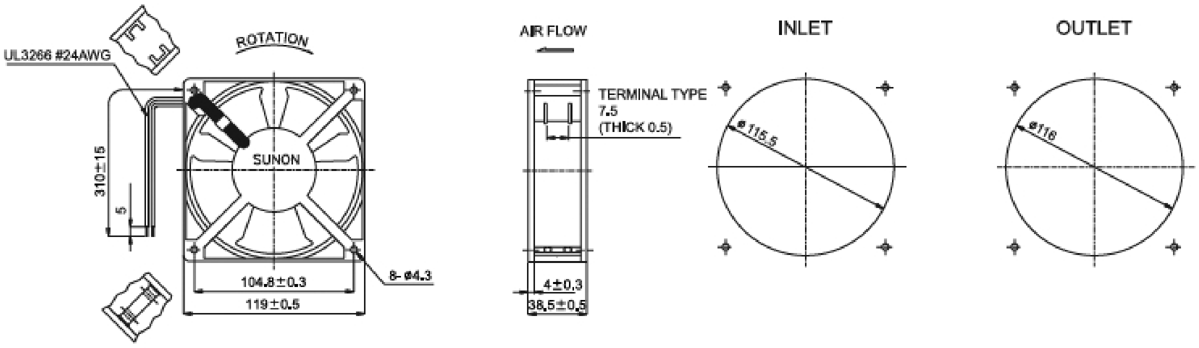

*All model could be customized on voltage or any other requirements to fit your need.
*Specifications subject to change without notice. Please Visit SUNON web site at http://www.sunon.com for update information.